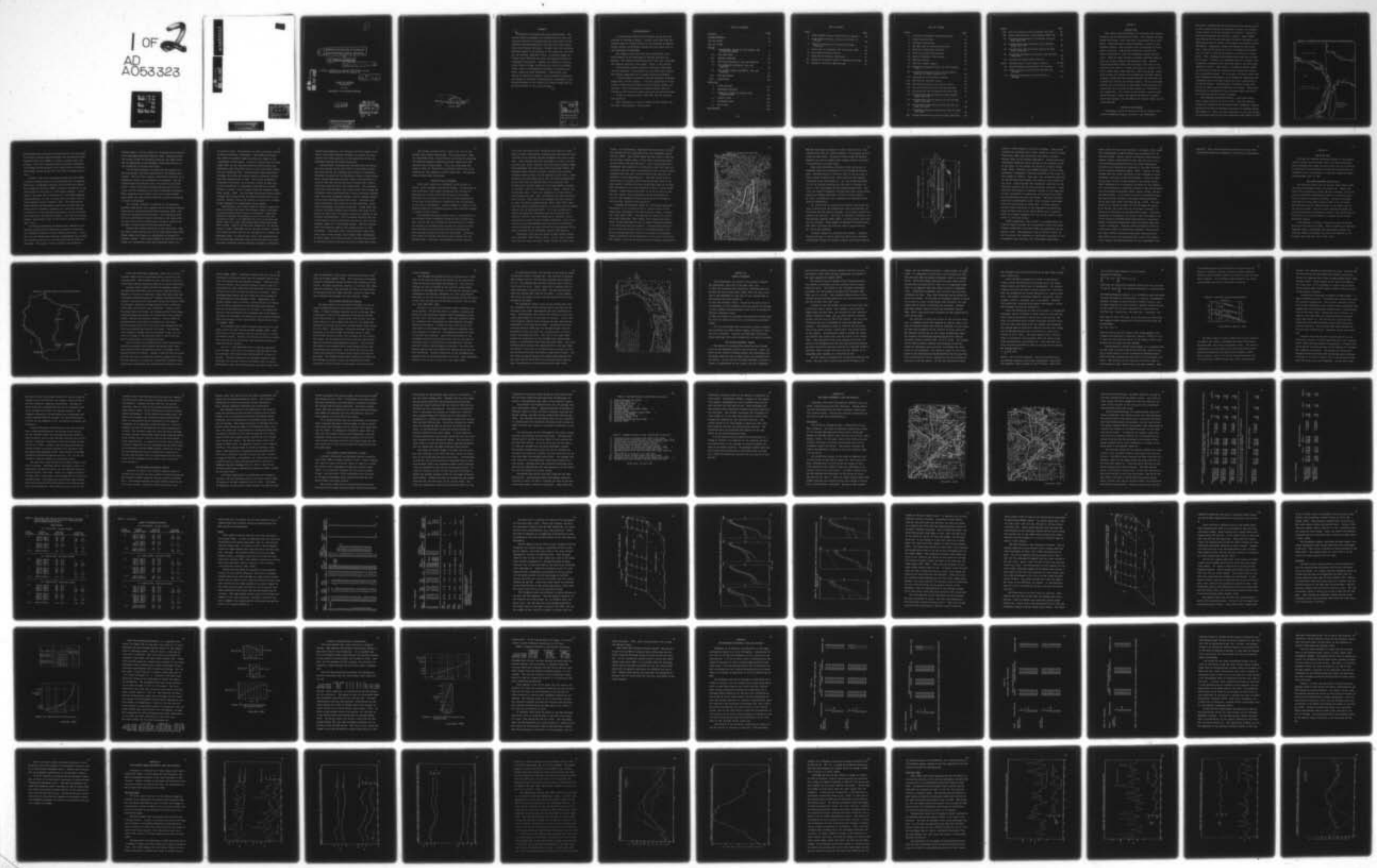
AD-A053 323 WISCONSIN UNIV-MADISON DEPT OF GEOGRAPHY F/G 8/8
GEOMORPHIC IMPLICATIONS OF FLOODPLAIN ENCROACHMENT NEAR PORTAGE--ETC(U)
1977 D H MADIGAN

UNCLASSIFIED NL

1 OF 2
AD
A053323



AD No.

DDC FILE COPY

6 GEOMORPHIC IMPLICATIONS OF FLOODPLAIN ENCROACHMENT NEAR PORTAGE, WISCONSIN.

BY

10 DOUGLAS HUGH MADIGAN

9 Master's thesis,

A thesis submitted in partial fulfillment of the requirements for the degree of

12 152 p.

MASTER OF SCIENCE
(Geography)

at the

UNIVERSITY OF WISCONSIN-MADISON

11 1977

408 531

Approved ______________________
George H. Dury, Chmn.

May 23, 1977

ABSTRACT

Floodplain encroachment has many ramifications. The present study investigates the possibilities of scour and excessive backwater resulting from the construction of the Columbia Generating Station on the Wisconsin River floodplain near Portage, Wisconsin. Neither scour nor excessive backwater appear to be problems in the study area, not even for the 100-year (regional) flood. A possible change in climate since 1950 does not alter the expected results of floodplain encroachment. However, the effects of the proposed climatic change, manifested by a shift from predominantly zonal to predominantly meridional circulation patterns, cannot be fully determined. Limited data, few choices of analytical methods, and the possible masking of any effects by reservoir development all contribute to the inconclusiveness of the analysis of climate change and its possible effects on the study problems.

ACKNOWLEDGEMENTS

I received much advice and assistance during the time involved in writing my thesis. Initial ideas came from discussions with Dr. Daniel Willard of the Institute of Environmental Studies and Professors George Dury and James Knox of the Department of Geography.

Not enough can be said about the contribution of Mr. Terry Hampton of the Department of Natural Resources in Madison. Mr. Hampton contributed much of his time, knowledge, and computer expertise to my study. Terry, I am grateful.

To my Thesis Committee members, Professors James Knox and John AuWerter, I am grateful for your editorial comments and helpful suggestions as to proper methods of analysis.

I cannot begin to thank my committee chairman, Professor George Dury, for his support. I am most appreciative of the speed in which my draft chapters were reviewed, edited, and returned. Your encouragement and moral support made the writing of this thesis an easier task than it could have been.

I want to thank my typist, Shar Day, for her interest and expertise.

Most importantly, I want to thank my wife, Connie, for her love, encouragement, and patience.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure		Page

CHAPTER I

INTRODUCTION

This thesis analyzes problems of increased water surface elevation and increased flow velocity. The problems, arising during flood flow, result from man's encroachment on a floodplain. Increased water surface elevation, a result of the backwater effect, could possibly cause overtopping of floodplain structures. High stream velocities increase the river's potential to scour the floodplain surface and features. Study of these hydraulic problems initially takes account of current climatic and hydrologic data. However, increasing evidence shows that Wisconsin, like most of the world for that matter, is being affected by a change in climatic regime (Lamb, 1966; Kalnicky, 1974; Knox et al., 1975). In an attempt to evaluate this possibility, climatic and hydrologic records for the periods 1873-1910 and 1925-1975 are examined for evidence of climatic change. The two geomorphic problems are re-examined, as hydrologic characteristics representative of the actual climate regime are considered in the reappraisal. The results of the present research demonstrate two major themes: the effects of man on a stream's flood flow regimen, and the effects of climatic change on the study problems.

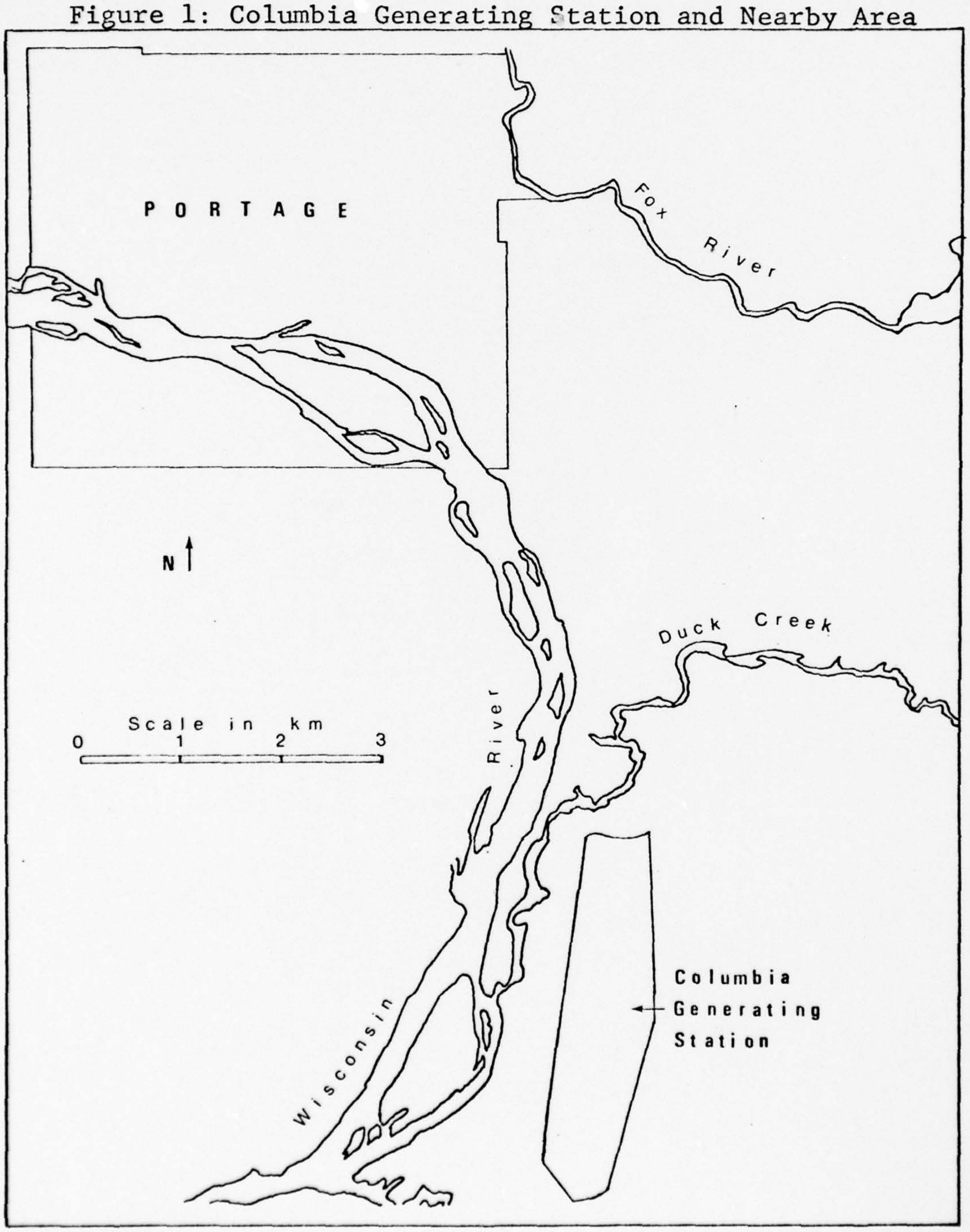
ORIGIN OF THE PROBLEM

Floodplains can be troublesome areas for people, especially floodplain managers, planners, and inhabitants.

Conversely, floodplains have historically been optimal places to live, whether because of proximity to water, of transportation routes, or of the location of factories. Floods can more than counteract the benefits, however. Kates (1962) investigated the reasons why people lived on floodplains and their perceptions of safety versus danger and benefits versus detriments. Apparently, people are willing to make trade-offs. They either accept or ignore the dangerous possibilities in order to receive the benefits of living on a floodplain. Thus, floodplain development and occupation continue to increase. Problems are compounded when one considers that floodplain occupation often adversely affects the hydrologic regimen of rivers. Two results, according to Wolman (1967), are increased runoff and sediment yield (especially during the construction phase). In an attempt to counter indiscriminate floodplain development, state floodplain regulations and a National Flood Insurance Program have been established in the United States. Unfortunately, floodplain zoning ordinances are often vague and difficult to enforce. Enforcement difficulty is manifested in the situation which occurred at the study site of the present research.

The Columbia Generating Station, a coal-fired power plant, began operation in March, 1975. This 527-megawatt station is located on the Wisconsin River floodplain, approximately 6.4 km south of Portage, Wisconsin, in Columbia County (See Figure 1). There was much opposition to the construction of this plant when it was first proposed to the public in 1971.

Figure 1: Columbia Generating Station and Nearby Area



Environmentalists and other concerned parties took advantage of the then recently approved federal law, the National Environmental Policy Act (NEPA), in order to express their misgivings. Most were concerned with the possible atmospheric and biologic pollution which could result from the sulfur dioxide (SO_2) content in the coal to be used in energy production.

However, others were concerned because the plant would by wholly situated on part of the Wisconsin River floodplain. Thomas Lee, a hydrologic engineer with the Wisconsin Department of Natural Resources (DNR), voiced his opposition to the construction of the plant at a 1971 public hearing. In his opinion, the plant was in violation of a 1965 DNR floodplain zoning ordinance, in that it would create a greater than allowed backwater effect (Schmied, 1973). The Environmental Impact Reports and Statements associated with the plant construction also alluded to backwater as a potential problem, in addition to other hydrologic phenomena, such as increased flow velocities, flow pattern changes, scour and fill pattern changes, and possible scour of the plant's cooling lake dike (EIS, 1974).

The various objections and doubts went unheeded as the Columbia County Board of Adjustments granted a variance to the floodplain ordinance in favor of the power plant. Possibly, the tax island which could be established by the utility tax revenues meant more to the officials than did their environment. The impact of the tax benefit was studied by

Michael Shaver, a former student in the University of Wisconsin's Geography Department (Shaver, 1976). Whatever may be the reasons behind the decisions involved, the final result was the appearance of the Columbia I Generating Station on the floodplain of the Wisconsin River.

In the final analysis, it seems that the progress of man must prevail over the preservation of the natural environment. All too often, however, alternative solutions to a problem are either not considered or are ignored. Did the Columbia Generating Station have to be built on the floodplain? Could it have been situated farther away from the river, off the floodplain, and still accomplish its purpose? These questions are now moot in the case of the Columbia power plant, but they can and should be carefully considered in future developments.

The present research, in addition to the backwater problem raised by Mr. Lee, examines one of the major problems discussed in the Environmental Impact Statement (EIS): the effect of increased flow velocities. These hydraulic problems are considered not only in relation to the study site, but also with a view to developing a method of analysis applicable to other sites of the same general kind.

Climate adds another dimension to the discussion. Knox and others (1975) demonstrated for the Upper Mississippi River Valley region that there is a significant persistence in climatic regimes. Their study refined the work done by Lamb (1966) on a hemispheric scale and by Kalnicky (1974) on a

continental scale. All proposed the need to consider climate as being essentially "nonrandom". Lamb (1966) postulated that shifts in climatic regime are due to a change in the tropospheric wind patterns. A shift is said to have occurred around 1960, as the long wave patterns shifted from a predominantly zonal (westerly) flow to a more meridional (northerly and southerly) flow. The meridional regime apparently resembles the cooler and moister pattern of general circulation that existed prior to 1895. The results of dominant meridional circulation are persistent periods of high year-to-year variability in temperature, precipitation, and hydrologic response, such as larger floods and sediment yields (Knox *et al.*, 1975). For the Upper Mississippi Valley region, droughts and extreme floods are alike characteristics of meridional regimes, whereas the frequent recurrence of droughty weather dominates in predominantly zonal regimes.

Significantly, this recent shift of climatic regime possibly establishes the facts that climate change is episodic and that weather-related events are nonrandom. Since most historical rainfall and streamflow records date back only 100 years at best, it is apparent that most of the data are biased toward the zonal flow regime that existed from about 1895 to 1960. Because of this zonal domination, the 30-year climatic normal, 1930-1960, may be the most abnormal "normal" that could have been used for the aggregation of climatic and hydrologic data. A question must arise: how representative are the existing hydrologic data and determinations of flood recurrence intervals used by floodplain managers, floodplain

construction engineers, and designers of flood control structures? The present research attempts to develop the topic, posed by the above question, in the examination of the two geomorphic problems discussed previously.

Both problems, backwater and increased flow velocities, may occur because of the power plant's occupation of space formerly used for the transport and storage of floodwaters. The plant's presence on the floodplain creates a constriction which, during high water periods, causes increased flow velocities near the constriction and increased water surface elevations upstream and at the constriction. The increased velocities could possibly cause scour, which could damage the floodplain surface and structures, lead to increased sediment load, and create ecological hazards, such as sediment deposition on fish-spawning grounds downstream. Increased water surface elevation, the result of too much backwater, could cause overtopping of upstream structures. Though other significant potential problems were raised by the Corps of Engineers in their EIS, the present research is limited to the problems aforementioned. This researcher believes that the study problems clearly demonstrate how man can alter the hydrologic regime of a river during floods. The two problems under investigation apply to any construction on a river floodplain. Since many rivers attain bankfull stage about once a year on the average, and inundate their floodplains at quite modest recurrence intervals, the phenomena created by the power plant's presence can recur at many other sites.

The present research fills a void in the work of the Columbia Site Impact Study Group. This organization, under the leadership of Dr. Daniel Willard, was formed to study the environmental impacts resulting from the construction and operation of the power plant. Since his group began the study in 1971, Dr. Willard has expressed a desire for an examination of the changes in surface water flow. The present study attempts that examination.

REVIEW OF THE LITERATURE

Three major topics are considered in the present research: scour, backwater and climate change. For purposes of this discussion, scour means entrainment and movement of particles as a result of the flow of water across them. Backwater is the increase in the water surface elevation of a river due to the effects of confluences and constrictions on the flow of floodwaters. Climate change is a shift in the dominant upper air circulation patterns with resultant changes in weather-related events.

The Columbia Generating Station forms a constriction on the Wisconsin River floodplain during periods of high water. Flow velocity (V) must increase at the constriction, because the presence of the power plant reduces the cross-sectional flow area (A) for a given amount of water discharge (Q) (the statement follows from the fact that Q=AV). Increased flow velocities provide increased erosive ability for the flowing water. Therefore, the floodplain surface and fea-

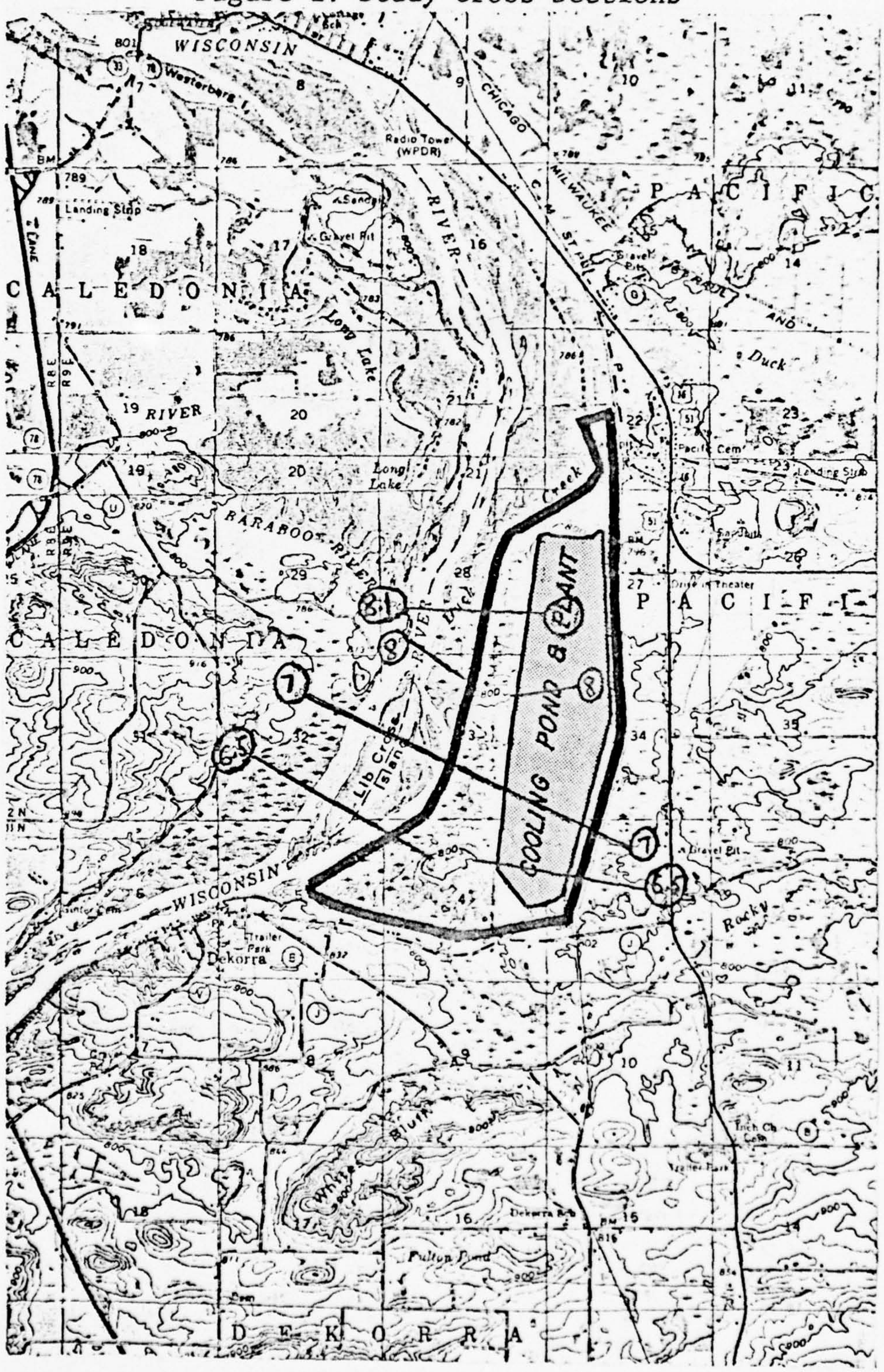
tures near the constriction should be more liable to scour than are other areas nearby, assuming that soil particle characteristics are sensibly uniform throughout the area in question. Scour depends upon flow hydraulics, as well as on the particle size, shape, density, and cohesiveness (Bryan, 1976). Flow hydraulics have been expressed by Leliavsky (1955), who indicates three controls on scour: critical flow velocity, critical tractive force, and the buoyant or lift force. Both Leliavsky and Graf (1971) agree that the field investigation of the lift force is impracticable at the present time. Critical flow velocity seems to be the most useful criterion to consider, since it is fairly easy to employ. However, uncertainties exist. There is a question as to what flow velocity should be used. Some researchers have used the bottom flow velocity, while others have employed the mean velocity as their threshold variable (Novak, 1973). Graf (1971) also cautions against indiscriminate use of critical velocity charts, such as that of Hjulström (1935). If study conditions resemble the empirical conditions used by researchers into critical velocity, then the method may be employed. Since the present research entails similar conditions, such as noncohesive soils and comparable particle sizes, the critical velocity threshold has been selected for investigation of the scour potential of the floodplain surface and features.

Floodplain scour has been noted in many studies (Jahns, 1947; Schmudde, 1963; Nelson, 1965). In all cases, however, the extent of scour was small, being limited to local occur-

rences. A low-frequency, high-magnitude flood event (50-100 year flood) did not appreciably scour the floodplain (Gupta and Fox, 1974). Dury (1973) found the same lack of scour for an even more extreme event--a flood with a recurrence interval of between 500 and 1000 years. Since the possibility of floodplain scour appears to be limited to small and local occurrences, map and visual reconnaissances near the power plant establish the area near cross-section 8 to be the most susceptible to scour (See Figure 2). Here the normal flow of flood waters is greatly constricted by the west dike of the power plant's cooling lake and a small knoll west of the dike. The constriction near cross-section 8 creates a narrow flood channel. Scour should occur here, if it is to occur at all. For that reason, the investigation of the possibility of scour of the floodplain surface and features is limited to the area that includes cross-section 8.

Although the backwater effect is a well-known hydraulic phenomenon, it is treated in only a cursory manner in the engineering textbooks of the West (Linsley, Kohler, and Paulhus, 1958; Ward, 1967). Considering the variety of studies on record (Rozenberg, 1972; Malik, 1971; Lodina and Chalov, 1971), Soviet hydrologists seem to regard backwater problems to be important areas of research. In engineering practice at the state and federal levels in the United States, computer programs have been written to calculate the backwater changes resulting from encroachments on the river's flow area. For example, the state of Iowa has its own program; Wisconsin's

Figure 2: Study Cross-Sections



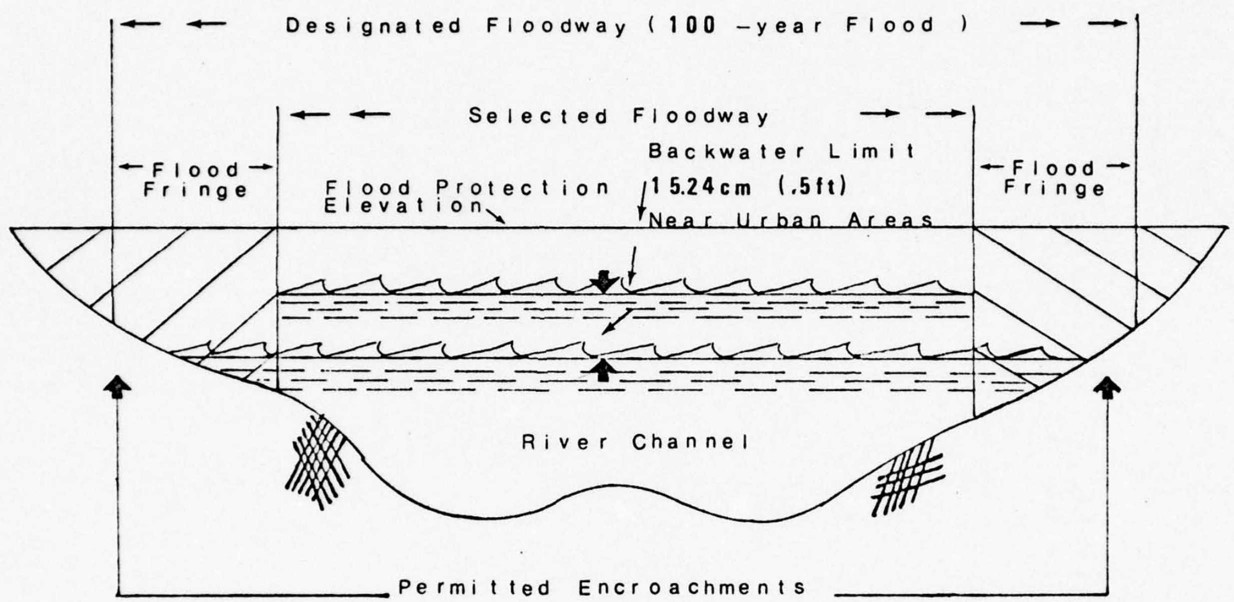
DNR uses the Corps of Engineer's model; while the U.S. Geological Survey has yet another program. All programs do basically the same thing. Bernoulli's Theorem and the Manning Equation are used to compute flow changes between successive cross-sections in a river reach.

Many state floodplain ordinances limit the amount of backwater that may be produced by a new floodplain development. Wisconsin places a 15.24 cm limit on the increase in water surface elevation near urban areas for the regional (100 year) flood (See Figure 3). Mr. Lee of DNR calculated a 15.54 cm increase upstream near the city of Portage, because of the encroachment of the Columbia power plant. However, the Corps of Engineers and the power plant construction engineers, Sargent and Lundy, arrived at lesser figures. Mr. Lee's testimony was not accepted by the Columbia County Board of Adjustments.

Dr. Willard of the Columbia Site Impact Study Group has been concerned with the disagreement about the backwater effect since the 1971 public hearings. The present research reexamines the question. The Corps of Engineer's backwater surface profile computer model, HEC-2, is the research tool used for the analysis. This program is employed by the Wisconsin DNR today, replacing the state of Iowa's program used by Mr. Lee in his analysis.

Climatic change is a controversial subject. Abundant theories attempt to relate long-term, short-term, periodic, and episodic changes in climatic regimes and weather-related

Figure 3: Backwater Limitations



(from Parrett, 1973, p. 88)

events to some variable or group of variables. The present research is concerned with a recent change in climatic regime. Since about 1960, many researchers have noted a general cooling trend in the northern hemisphere. Surface and ocean temperature anomalies and an increase in the southern extent of the polar ice cap support the belief in climatic change (Lamb, 1972). Earlier, Lamb (1966) proposed a shift in the predominant tropospheric long wave patterns as the reason for this change in climate. These upper air circulation patterns are the driving forces behind the climate at the surface of the earth. Lamb propounds that meridional components in the long wave patterns are now the predominant situation. These northerly and southerly components account for the high year-to-year variability in temperature and precipitation which has characterized the past two decades. The prior climatic regime was predominantly zonal. Thus, westerly winds dominated the period prior to about 1960. In North America, westerly winds contribute to the orographic precipitation along the West Coast of the United States and a generally warm, dry climate throughout the rest of the country, especially in the Great Plains.

Lamb's hypothesis, that a shift to a predominantly meridional regime accounts for the generally cooler and wetter climatic conditions since about 1960, has proponents and opponents alike. Some opponents, such as Willett (1975), do not even accept the dominance of meridional components in the tropospheric wave patterns, let alone Lamb's hypothesis.

Recent data cloud the issue somewhat. Brinkmann (1976) found that temperatures in North America have increased 0.2°C in the past decade. Mason's speech to England's Royal Meteorological Society establishes the facts that the polar ice is now retreating northward and that the colder temperature anomalies are decreasing in frequency in the high latitudes of the northern hemisphere (Mason, 1976). However, he does concede that the cooler and wetter trend, although of lesser intensity, continues in the mid-latitudes. Since the upper air patterns control surface weather in the United States, Lamb's hypothesis is a reasonable statement for the temperature and precipitation anomalies recorded in the United States and investigated by Kalnicky (1974), Namias (1970), and Knox and others (1975). A noticeable increase in meridional long wave patterns has occurred in the Upper Mississippi River Valley area since about 1950 (Knox _et_ _al_., 1975). The same situation is assumed to hold true for the Upper Wisconsin River Valley, the study area for the present research, because of its proximity to the Upper Mississippi. With this assumption as background, the present study investigates one of the climatic variables which characterizes a meridional regime--increased precipitation characterized by high year-to-year variability. Kalnicky (1974) and Namias (1970) focused their studies on temperature anomalies, whereas Knox and others (1975) examined precipitation characteristics. Lamb (1972) states that precipitation, better than temperature, reflects the characteristics of the tropospheric wave

patterns. Thus, only precipitation data for the Upper Wisconsin River Valley are examined in the present investigation.

CHAPTER II

THE STUDY AREA

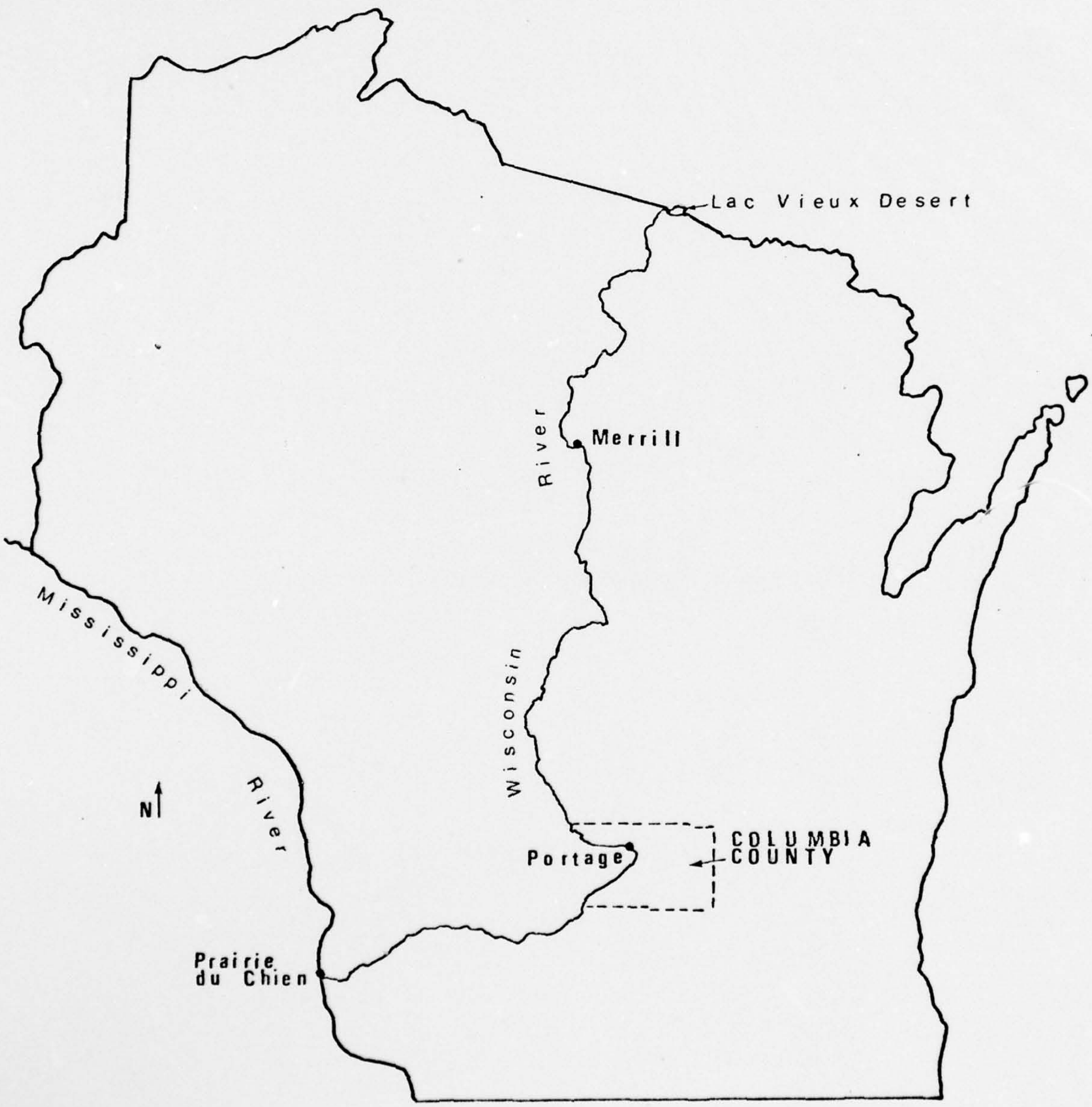
Although the Columbia Generating Station is the primary area of concern in the present study, the entire Wisconsin River drainage basin above the power plant must be considered. 'A downstream site investigation should not be undertaken in isolation from a consideration of upstream conditions' (Cooke and Doornkamp, 1974, p. 88).

THE UPPER WISCONSIN RIVER VALLEY

The Wisconsin River rises in the Lac Vieux Desert along the Wisconsin-Michigan border (See Figure 4). Thence the river flows southward for about 482 km to Portage, then turns westward and flows approximately 190 km to the Mississippi River at Prairie du Chien, Wisconsin. Elevation decreases from 502.9 m at the river's head to 184.1 m at its mouth, with greatest rate of slope decrease in the upper third of the river's length. The river flows through glaciated and non-glaciated parts of Wisconsin; however, the reach from Lac Vieux Desert to the power plant is situated wholly within glaciated terrain.

Above Nekoosa, resistant, crystalline rocks of Precambrian age form numerous rapids. Softer sandstone of the Upper Cambrian Group, covered with sand and gravel, account for shifting sandbars throughout the reach from Nekoosa to the Columbia plant (Herron, 1917; Mead, 1911).

Figure 4: The Main Stem of the Wisconsin River



Level and undulating topography, except for a few noticeable ridges such as the Baraboo Hills, prevails in the drainage basin. River bluffs are few, but those at the Wisconsin Dells and the narrows at Dekorra are quite spectacular.

Lawrence Martin (1932) divided the drainage system of the Upper Wisconsin River into two parts, with the city of Merrill as the point of division. Many lakes and swamps and a drainage network described as "crooked, systemless stream courses" characterize the area north of Merrill (Martin, 1932). A systematic, dendritic drainage pattern with no lakes describes most of the basin south of Merrill. However, from Wisconsin Rapids to Portage, an "aimless pattern" with large, undrained interstream areas, few tributaries, and a shallow valley, replaces the dendritic pattern. Martin (1932) hypothesized that the absence of tributaries and a well-defined valley may be due to the short time during which the river has occupied this part of its course. The drainage near Portage is thought to be late glacial in age, as a result of a change in the Wisconsin River's course from the Devil's Lake gorge to its present position.

The river water is reddish-brown in color because of industrial by-products and inorganic pollutants (EIS, 1974). The sediment load of the Wisconsin River is thought to be composed mostly of bedload. Though no bedload data are available for the river, qualitative estimates suggest that significant quantities of sand are transported--enough to cause troublesome recreational and developmental problems in many

areas (UMCBS, 1970). Suspended sediment data for some of the Wisconsin's tributaries show that the suspended load is very low, much below state and national averages. From Lac Vieux Desert to Wausau, the suspended sediment yield is only 3.5 tonnes/km^2 per year, while the load increases to 10.5 tonnes/km^2 per year in the stretch from Wausau to Portage. These suspended load figures are well below the state average of 28 tonnes/km^2 per year (Hindall, 1976). Apparently, suspended sediment load is minimal in glaciated parts of Wisconsin, but often significant in the non-glaciated Driftless Area of the southwestern part of the state. No analyses of particle size distribution for suspended load of the Wisconsin River are available, but fine clay sizes probably dominate. Small percentages of fine sand and silt should also be present (UMCBS, 1970).

The average annual runoff decreases from 33.0 cm in the north to 20.3 cm near Prairie du Chien (UMCBS, 1970). Most flood flows on the Wisconsin occur in the spring as a result of snowmelt runoff. However, the disastrous floods on record have occurred in the late summer and early fall because of large amounts of rainfall.

The flow of the Wisconsin River is heavily regulated. Above Portage, there are 21 reservoirs (493,200,000 m^3 storage capacity) and 3 power dams (328,594,500 m^3 storage capacity). These 24 reservoirs and flowages stabilize river discharge for purposes of power utilization and recreation. Additionally, many small hydroelectric dams and 3 large flow-

ages (at Petenwell, Castle Rock, and Wisconsin Dells) exist north of Portage (UMCBS, 1970). The reservoirs and flowages provide a significant amount of flood flow regulation in the spring. Of great importance, however, is the fact that these dams and reservoirs have virtually no effect on flood flows at Portage during the summer and fall, because at that time the reservoirs and flowages are full (Sherrar, 1976a).

THE COLUMBIA GENERATING STATION

The power plant is 6.4 km south of Portage, in the extreme southeastern part of the Central Sand Plain (Martin, 1932). A unique drainage situation exists at Portage, where a distance of only 2.4 km separates the Wisconsin and Fox Rivers (See Figure 1). During normal flow periods, the Wisconsin River is 1.83 m higher than the Fox; the height difference may increase up to 6.10 m during extreme flood events (C of E, 1971). Historically, interbasin drainage from the Wisconsin to the Fox through the Portage canal (a canal 15.24 m wide and 0.61 m deep, that connects the two rivers), Duck Creek, and low-lying areas both north and south of Portage has occurred during high-water periods. Levees along the banks of the Wisconsin River near Portage protect that city during most flood flows. The levees also prevent any widespread drainage of Wisconsin River waters into the Fox watershed. The Columbia power plant could have an effect on the drainage situation, because of the backwater effect created by the power plant's encroachment on the Wisconsin

River floodplain.

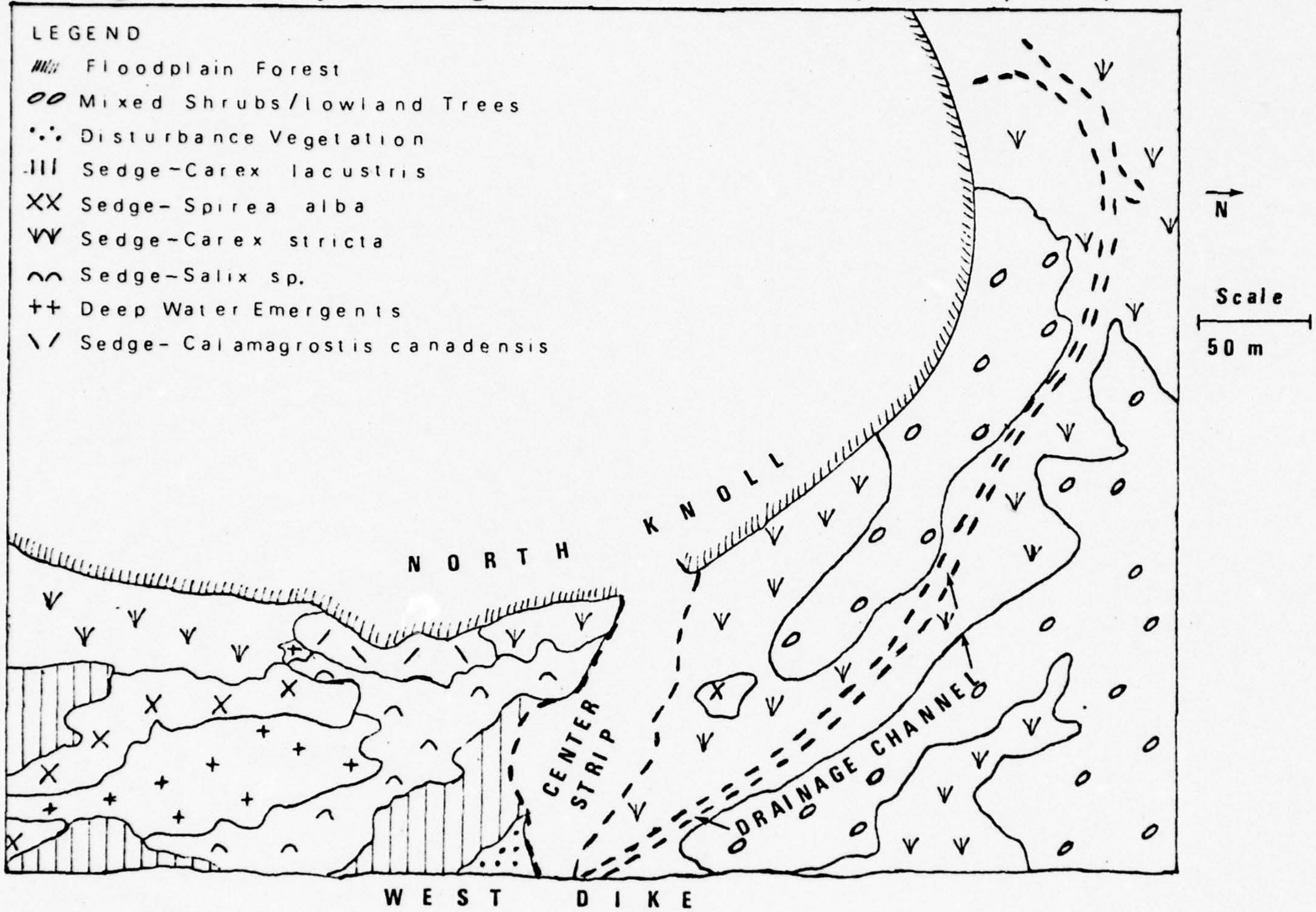
The Columbia Generating Station is located on an 11 km^2 site in the towns of Dekorra and Pacific on the east floodplain of the Wisconsin River (See Figure 1). The land comprising the site is bounded on the south by county trunk highway VJ and Rocky Run Creek; on the east by railroad tracks belonging to the Chicago, Milwaukee, St. Paul, and Pacific Railroad; on the west by the Wisconsin River; and on the north by the north section line of Sections 21 and 22, Town of Pacific, T12N, R9E (EIS, 1974).

The site is in an area of glacial drift overlying sandstone bedrock. The glacial drift, an aquifer, consists primarily of sand and gravel deposits with intermingled lenses of clay, silt, and coarse gravel. Surficial materials above the sandstone also include glacial lake deposits averaging 30.48 m in thickness. A series of test wells in the area show depth to the bedrock of Upper Cambrian sandstone somewhere between 21 m and 43 m. Precambrian crystalline rocks lie beneath the sandstone. The surficial material on the floodplain between the Wisconsin River and the west dike of the power plant's cooling lake is heterogeneous, with substantial vertical and horizontal variations. The surficial glacial deposts have been modified by fluvial action and surface weathering. Sediment deposition on the floodplain has occurred over the western portion of the site. Some windblown deposits exist in the eastern site area (EIS, 1974).

An important feature, for purposes of the present study, is the power plant's cooling lake. The lake has an approximate surface area of 1.94 km^2 and an average water depth of 2.74 m. The cooling lake normally contains about 4.67 billion liters of water. Dikes, composed of compacted fill of local materials, surround the lake. Rip-rap and bentonite cover the cooling lake sides of the dikes. A thin organic soil layer and sparse grasses top the compacted fill on the outside of the dikes.

The floodplain surface, west of the cooling lake, and the floodplain side of the cooling lake's west dike are the principal areas under investigation for the possibility of scour. Specifically, the area in the vicinity of cross section 8 (See Figure 5) is the place of interest. Here a narrow floodplain channel exists between the west dike and the sandy knoll to the west of the dike. Preliminary Soil Conservation Service (SCS) maps for Columbia County show the floodplain surface in this area, a sedge meadow, to have a Lapeer fine sandy loam soil. The soil on the sandy knoll, labeled the North Knoll by the Columbia Site Impact Study Group, is a Plainfield loamy fine sand (EIS, 1974). The local materials which compose the compacted fill in the west dike are similar to the soil on the North Knoll, because the fill was extracted from this and similar sandy knolls nearby. Surface soils currently found in the sedge meadow between the west dike and the North Knoll are primarily either sand or peat, distributed in a non-uniform fashion (EIS, 1974).

Figure 5: Study Site Vegetation and Soils (from IES, 1976)



CHAPTER III

GENERAL PROCEDURE

Three hypotheses are tested in the present research. The hypotheses, expressed in the null form, are:

1) That the increased flow velocities, resulting from the presence of the Columbia power plant, will not cause scouring of the floodplain or west dike of the cooling lake in the vicinity of cross-section 8.

2) That the backwater effect, created by the power plant's encroachment on the floodplain, will not produce an increase in water surface elevation greater than 15.24 cm during the 100-year (regional) flood.

3) That the climate in the Upper Wisconsin River Valley does not have the characteristics of a predominantly meridional regime.

If it is determined that the present climate resembles the meridional pre-1895 climatic regime, hypotheses 1 and 2 will be re-examined. Climatic and hydrologic data which should represent the actual climate will be used if possible.

THE SCOUR HYPOTHESIS: METHOD

The effect of increased flow velocities may include scour of the floodplain surface and structures. Scour can occur if the velocity increase permits the achievement of a threshold value for some variable which can initiate particle motion. The use of the threshold variable, critical velocity, is appropriate if one assumes that the floodplain

and west dike surfaces possess specific critical velocity thresholds, rather than intrinsic geomorphic thresholds of the type suggested by Schumm (1973).

The present research employs a Soil Conservation Service method to determine critical velocity and the possibility of scour. The method is the "allowable velocities procedure" for the design of unlined earth channels (SCS, 1964, pp. 6-1 to 6-9). The procedure employs charts to determine the non-scouring velocities that can be tolerated by the soil before scour will occur.

In order to use the method, certain soil and water characteristics must be known. Soil samples, taken from the sedge meadow and west dike, are analyzed for soil classification, plasticity index, and D_{75} (soil particle diameter greater than the size of 75% of the sample). The soil classification and D_{75} are obtained by sieve and hydrometer analysis. The plasticity index is found by the determination of the water content, liquid limit, and plastic limit of the samples. The plasticity index is simply the difference between the liquid limit and the plastic limit (Lambe, 1951). The character of the water flowing across the surfaces of the floodplain and the west dike was determined by personal observation and grab sampling of suspended sediment. Character refers to what the water carries, whether it be suspended load, bedload, or no detritus at all.

The SCS method is designed for unvegetated channels and banks. The west dike, nearly covered with bluegrass and

sedges, and the floodplain surface, a sedge meadow, are vegetated. To compensate for this fact, the assumption is made that the west dike and nearby floodplain surface are unvegetated. If the SCS method indicates the areas under consideration have no potential for scour in an unvegetated condition, it is apparent that they cannot scour in a vegetated state. Vegetation strengthens soil structure and increases resistance to flow. Thus, flow velocities and potential for scour are reduced. If the dike or floodplain surface is found to be prone to scour, an SCS method that considers the vegetation can be used to investigate the situation. However, with this method, which is based upon retardance factors (SCS, 1954), only qualitative estimates of the possibility of scour can be made.

The question of scour now centers on the critical velocity. A somewhat theoretical approach is used in order to arrive at velocity values that could be expected to occur along the dike and floodplain in the vicinity of cross-section 8. The approach entails the use of a Corps of Engineers computer program, the Hydrologic Engineering Center-2 (HEC-2) backwater surface profile model (C of E, 1973). The program can be used to obtain velocity distributions across the length of individual cross-sections, to include the velocities on the floodplain. The velocity values on the floodplain in the reach between the North Knoll and the west dike near cross-section 8 can be compared to the non-scouring velocities on the SCS charts. If the flow velocities exceed

the allowable velocities determined by the SCS (1964) method, scour could occur.

Since the HEC-2 program is so vital to the present study, a brief discussion of the program and of its underlying theories and limitations is appropriate. The program computes and plots the water surface profile for river channels and floodplains for either subcritical or supercritical flow. The effects of various hydraulic structures, such as bridges, culverts, and dams, may be considered. Modified flow conditions resulting from channel improvements, levees, and floodways can also be allowed for.

Given the dimensions of each cross-section, a designated discharge, and an estimated or known value for the starting water surface elevation at the initial cross-section, the model can calculate water surface elevations and flow velocities at each cross-section for the channel and floodplain. The program applies Bernoulli's Theorem for the total energy and the Manning Equation for the velocity at each cross-section (C of E, 1973). The model applies these relationships to successive cross-sections until the entire reach under investigation is accounted for. The essential equations are here presented in order to clarify the discussion. The Manning Equation:

$$V = \frac{1}{n} R^{2/3} S^{1/2},$$

where V, the velocity (unknown), equals one divided by n, the Manning roughness coefficient (estimated), times $R^{2/3}$, the hydraulic radius (known) to the $^{2/3}$ power, times $S^{1/2}$,

the riverbed slope (known) to the 1/2 power.

Bernoulli's Equation:

$$\frac{V_1^2}{2g} + D_1 + Z_1 = \frac{V_2^2}{2g} + D_2 + Z_2 + h_L$$

expresses the energy relationships between two cross-sections (1 and 2), where $\frac{V_1^2}{2g}$, the velocity head (V_1^2 is velocity from the Manning Equation squared; it is divided by twice the gravitational constant) at cross-section 1, plus D_1, the hydraulic gradient or depth at cross-section 1 (known), plus Z_1, the riverbed elevation at cross-section 1 (known), equals the sum of the values for the same variables for cross-section 2 ($V_2^2/2g + D_2 + Z_2$) plus h_L, the head loss. Generally, the head loss is due to friction, so $h_L \approx h_F$ (friction head loss). The computer model computes the friction head loss with the relationship:

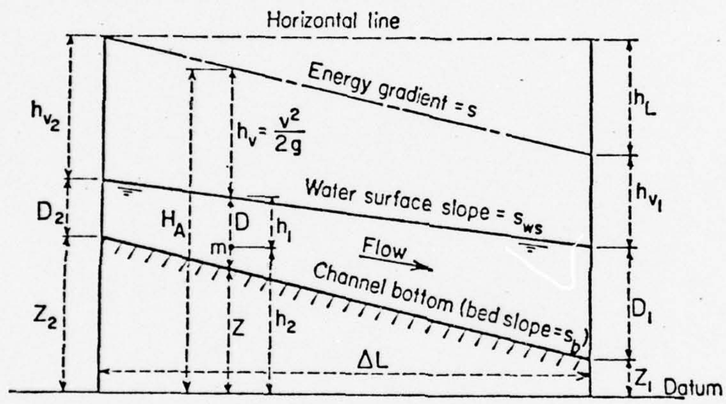
$$h_F = S_2 + S_1 \Delta L,$$

where S_2 and S_1 are the slopes of the energy gradient (obtainable from Bernoulli's Equation, since $S = V^2/2g + D + Z$) at the two cross-sections and ΔL is the length of the reach between the two cross-sections (known).

From Bernoulli's energy relationship, it is apparent that all the terms on either side of the equation, except for D_2 (D_1 is known since it is the estimated or otherwise determined starting elevation for the initial cross-section), are known. The equation can be solved for the water depth at cross-section 2 (D_2), because D_2 is the only unknown. Thus,

the Manning Equation and Bernoulli's Theorem enable the model to calculate velocity and water surface elevation, which are the variables needed in a study of scour and back-water problems. The following diagram depicts the energy relationship expressed by Bernoulli's Equation.

Figure 6: Bernoulli Energy Relationships



(from Simons, 1969, p. 134)

The HEC-2 model is widely employed by various agencies throughout the country, including the Corps of Engineers, Wisconsin DNR, and private engineering firms. The model is recognized as an outstanding tool when used with accurate data and interpreted with objectivity (Hampton, 1976). Other agencies, such as the United States Geological Survey and Bureau of Public Roads, have their own programs.

However, all programs are basically the same. The only difference between the USGS model and the HEC-2 program involves the computations of flow through bridges (Krug, 1976; Hampton, 1976). Since bridges do not affect the flow in the study area, it is reasonable to assume that any backwater profile model should produce similar results if used in the present research.

Limitations necessarily accompany the HEC-2 model. A major limitation is cost. Surveyed cross sections are vital for accurate computations. The present reserach is fortunate in that sufficient cross sections were surveyed for the engineering and environmental studies prior to the construction of the power plant. Twenty-one cross sections, surveyed in the early 1970s are contained within the study reach (See Figure 2). The sections are accurately described with 20 to 80 horizontal ground points and elevations per section. Cross-section data were reviewed for accuracy and simplification. Redundant points were elimated.

Computer time and operator salaries add to the cost limitation; however, the wide applicability of the computer output should provide adequate compensation. A bigger limitation may be the insensitivity of the Manning "n" variable, the roughness coefficient. The program can account for changes in flow resistance with increasing water discharge and depth in the river channel, but it cannot perform similarly for flow across the floodplain. On the other hand,

the model allows for multiple Manning "n" values along the length of the cross-section: for example, cross-section 8 has five different roughness coefficients. Manning "n" values from Lee's original DNR work on the backwater problem at Portage were used in the present analysis. The roughness values were checked against air photographs and on-site observations for accuracy, but for the most part, reliance on the judgement of Mr. Lee and his co-workers was necessary.

Another limitation of the model is the need to establish a starting elevation at the initial cross-section. For the 100-year flood, the starting elevation should be quite accurate, since it was obtained from the Corps of Engineers' floodplain information study for Portage, Wisconsin (C of E, 1972). However, the starting elevations for floods of other recurrence intervals were dependent upon the engineering judgement of Mr. Terry Hampton of the DNR Floodplain-Shoreland Management Section. Mr. Hampton ran the HEC-2 computer program for the present study.

The only other input needed for the HEC-2 model is the water discharge. Discharge values from Conger (1971), as modified by the USGS for the 2, 10, and 100-year floods at Wisconsin Dells, were used. There is no gaging station at Portage, only a crest gage, necessitating the use of Wisconsin Dells data. The program was run for all three floods with cross-sections that existed before the Columbia power plant was constructed. The outputs from the runs are the

"natural state" data which serve as the bases for comparison with output from runs which consider the power plant's encroachment. Program runs were made for the present situation, that is, with cross-sections affected by the power plant's dikes, and for the situation which considers double encroachment. In the double encroachment runs, the amount of conveyance lost because of the presence of the plant is subtracted from the conveyance on the opposite floodplain if the physical situation allows it. The same sequence of runs was followed for all three recurrence intervals. The velocity output for cross-section 8 provides the mean velocity values which should occur along the floodplain surface and west dike for each of the three floods under consideration. A comparison of these values with the allowable velocities for the floodplain and west dike soils, as determined by the SCS (1964) method, allows one to test the first hypothesis--that increased flow velocities resulting from the power plant's encroachment will not cause scour of the floodplain or west dike in the vicinity of cross-section 8.

THE BACKWATER HYPOTHESIS: METHOD

Analysis of output from the HEC-2 computer model determines the increases in water surface elevation because of the backwater effect caused by the power plant's encroachment. The program computes the water surface elevation for each cross section. Elevation differences between the

natural state runs and the runs for double encroachment are results of the proposed backwater effect. The elevation differences at each cross section are the increases in water surface elevation resulting from encroachment.

The backwater effect is of significance, not only because the increase in water surface elevation may be large enough to be in violation of the state floodplain zoning ordinance, but also because of its possible impact on the city of Portage. Some flood protection is afforded the city by the levees along the banks of the Wisconsin River; however, the levees are only expected to withstand floods with recurrence intervals of less than 10 years (C of E, 1971). Larger floods with stages greater than 242.32 m at Portage will overtop the levees. The 100-year flood, with a discharge of 2690.4 m^3/s, is expected to have a river stage of 242.93 m. The largest flood on record at Portage, a September 1938 flood with a discharge of approximately 2044.7 m^3/s and a recurrence interval of about 10 years, reached a stage of 242.50 m. Fortunately, the levees were not overtopped because an early warning allowed the citizens to heighten them with sandbags (C of E, 1971). None of the aforementioned figures consider the backwater effect created by the power plant.

A further complication for inhabitants of Portage is the fact that the existing levees do not meet current Corps of Engineers and DNR standards (C of E, 1971). The Corps of Engineers estimates that annual damages from hypothetical

floods exceeding levee design height would average $225,000 for Portage (C of E, 1971). Preliminary improvement plans have been formulated, and some money is presently available for initial work on flood protection. The Corps of Engineers, DNR, and the Department of Housing and Urban Development (HUD) are involved, but the end-product of their efforts appears to be far off in the future.

It is quite possible that the encroachment of the power plant increases the water surface height to such an extent that floods more frequent than the 10-year event might overtop the levees. An analysis of the HEC-2 output will not only test the present study's second hypothesis, that the backwater effect will not create a greater than 15.24 cm water surface elevation increase at Portage during the 100-year flood, but it will also evaluate the significant problem posed above.

THE CLIMATIC CHANGE HYPOTHESIS: METHOD

A global cooling with accompanying rainfall anomalies since about 1960 is widely accepted as fact. Lamb's hypothesis, that the cooler and wetter regime of today is a result of a shift in the tropospheric long wave patterns (Lamb, 1966), is a reasonable statement for the recent climatic change. Knox and other (1975) investigated the situation in the Upper Mississippi River Valley and found the proposed change to be quite evident.

The present study analyzes precipitation and streamflow data for the Upper Wisconsin River Valley from the Lac

Vieux Desert to the Columbia power plant in an attempt to test for such a change there. Rainfall and low flow stages for the period 1873-1910 and precipitation and mean discharge per square kilometer for the interval 1925-1975 are the data for the investigation. The data are evaluated in order to determine the presence or absence of a trend toward a greater degree of wetness and of a persistence of variability in rainfall and hydrologic response for the pre-1895 and post-1950 periods. Persistent variability results from the alternating flow of air from the north and the south, as the meridional circulation pattern blocks the westerly airflow of the zonal regime. A trend toward increased precipitation would result primarily from the southerly component of the meridional regime. The incursion of warm, moist air from the Gulf of Mexico enhances precipitation in regions like the Upper Wisconsin River Valley.

The study of climate change is divided into two parts. The first pertains to the 1873-1910 data, while the second part is concerned with the more recent data. Precipitation records for the initial period were obtained from an early work by Mead (1911), who examined rainfall-runoff relationships in Wisconsin at the turn of the present century. He used five weather stations located upstream of Portage to obtain his monthly rainfall totals for the Upper Wisconsin River Valley. Monthly low flows at Portage are the streamflow data for the first part of the climate study. Low flows are appropriate, because the Wisconsin River was not

regulated to any great extent during the 1873-1910 period. The low flows should be good indicators of hydrologic response to precipitation and, thus, to the climatic regime.

The rainfall and streamflow data sets are grouped into three hydrologic seasons. Monthly groupings of November to February, March to June, and July to October represent the Winter, Spring, and Fall seasons respectively (Knox et al., 1975). The rainfall and streamflow data are also expressed as running means and cumulative deviations from the mean in order to detect any trends or persistent variability in the data.

The second part of the investigation of climate change involves the analysis of more recent data. Precipitation totals from 13 weather stations (Table 1) are examined for the 1925-1975 period. As in the first part of the study, the data are divided into the three hydrologic seasons. The monthly precipitation totals for the 13 stations are averaged to provide one rainfall value per month for the entire area above the Columbia power plant. The average rainfall values for each hydrologic season are presented in a time series. Running means and cumulative deviations from the mean are employed for the same purposes as in the first part of the analysis of climate change.

Streamflow data differ from those used for the 1873-1910 period. The Wisconsin Valley Improvement Authority received a charter in 1907 to regulate the flow of the Wisconsin River with a series of reservoirs. Power dams and

Table 1: Weather Stations and Periods of Record

1. Phelps Deerskin Dam (1945-)
2. Rest Lake (1913-)
3. Long Lake Dam (1908-)
4. Minoqua Dam (1903-)
5. Rhinelander (1891-)
6. Tomahawk Spirit Reservoir (1902-)
7. Merrill (1905-)
8. Marshfield Experimental Farm (1912-)
9. Stevens Point (1893-)
10. Wisconsin Rapids (1921-)
11. Coddington (1921-)
12. Hancock Experimental Farm (1902-)
13. Mauston (1891-)

Table 2: Gaging Stations, Areas, and Periods of Record

1. Wisconsin River at Rainbow Lake 1942.5 km^2 (1936-)
2. Tomahawk River at Bradley 1411.6 km^2 (1930-September 1973)
3. Spirit River at Spirit Falls 212.4 km^2 (1942-)
4. Prairie River near Merrill 468.km^2 (1939-)
5. Wisconsin River at Merrill 7200.2 km^2 (1902-)
6. Eau Claire River at Kelly 844.3 km^2 (1914-26, 1939-)
7. Wisconsin River at Rothschild 10360 km^2 (1944-)
8. Big Eau Pleine River near Stratford 580.2 km^2 (1914-25, 37-)
9. Yellow River at Babcock 577.6 km^2 (1944-)
10. Lemonweir River at New Lisbon 1295 km2 (1944-)
11. Wisconsin River at Wisconsin Dells 20279.7 km^2 (1934-)
12. Baraboo River near Baraboo 1554 km^2 (1913-22, 1942-)

Total Area: 46,725.5 km^2

additional reservoirs added to the degree of regulation in later years. Lew Sherrar (1976b), a manager of the regulatory agency, recommended the use of monthly mean flow per unit area for the 1925-1975 period. Mean discharges are used because river regulation provides unnatural control on the low flows. Mean monthly discharges for 12 gaging stations (Table 2) in the Upper Wisconsin River Valley above Portage are examined for the 1941-1973 interval. The stream record is not long enough to employ the same 1925-1975 interval used for the precipitation analysis. The streamflow data are presented and analyzed in the same manner as are the precipitation data.

A final measure used to examine the possibility of a change in climate is an analysis of the temporal and absolute differences in the averages of monthly rainfall for each of 13 weather stations. The monthly rainfall data for each station are divided into a 1925-1949 zonal interval and a 1950-1975 meridional interval for the purpose of comparison.

CHAPTER IV

THE SCOUR HYPOTHESIS: DATA AND ANALYSIS

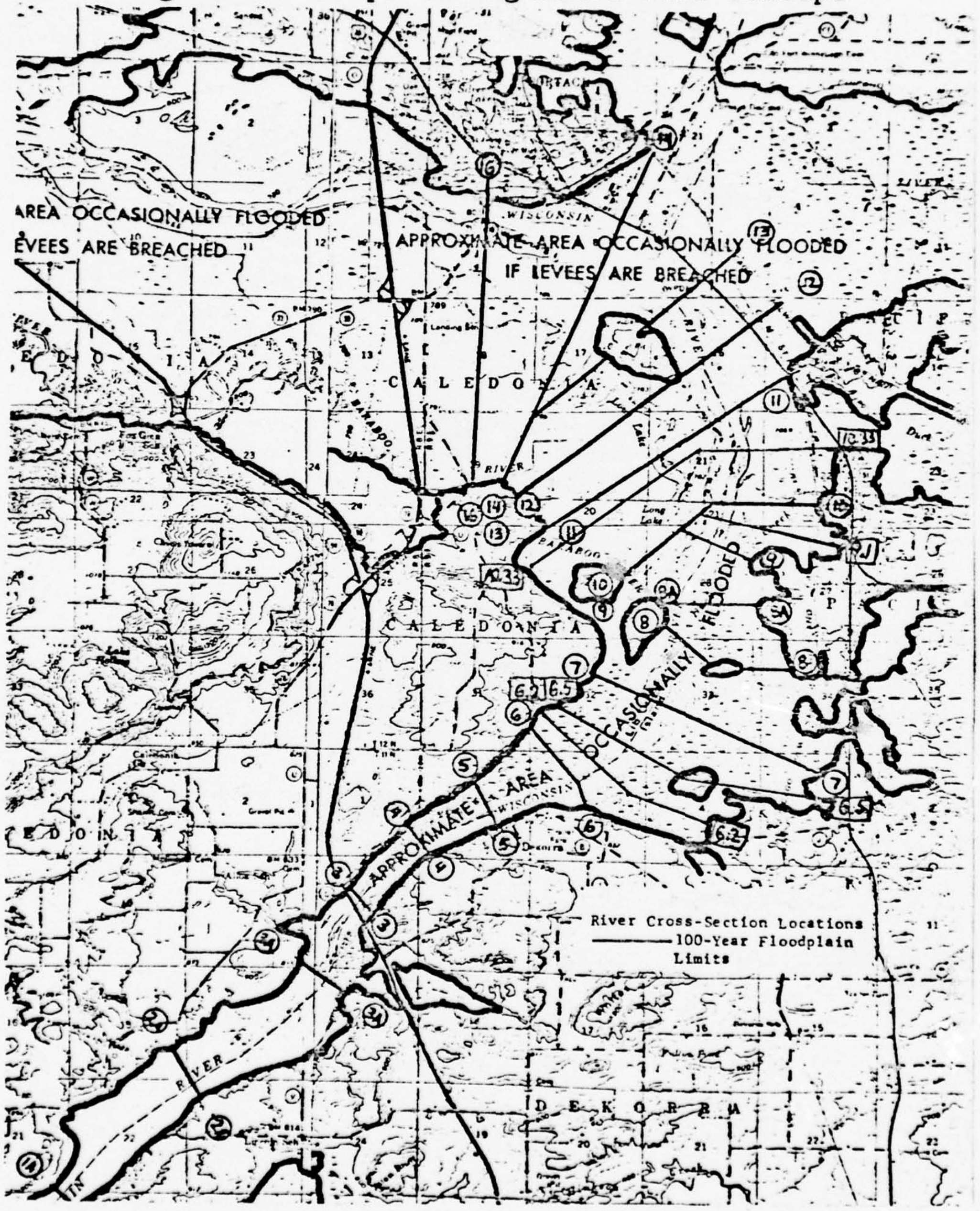
Basically, the scour investigation considers two variables: stream velocity and soil character. Stream velocities are determined with the HEC-2 backwater surface profile computer model. Various soil analysis techniques provide data on the soil characteristics.

Velocities

The levees at Portage present a complication in the HEC-2 analysis. The Corps of Engineers expects the levees to fail during high-magnitude flood events, whereas Mr. Hampton of the DNR suspects that they may not (C of E, 1971; Hampton, 1976). In the upper reach of the study area near Portage, the latter situation would confine most of the floodwater inside the levees. The present research considers both hydraulic settings in the scour analysis (Figures 7A and B).

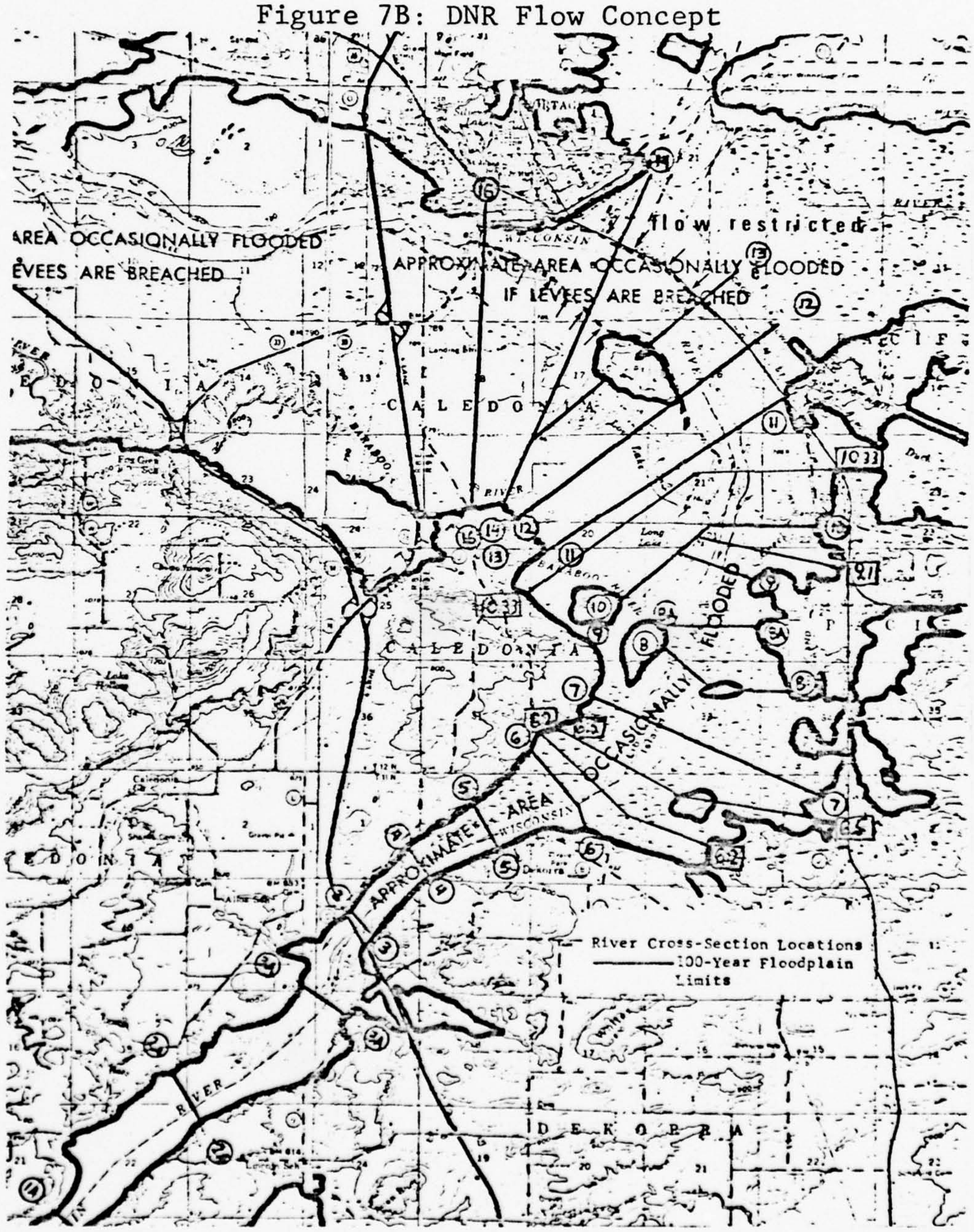
The water flow concept of the Corps of Engineers for extreme floods is depicted in Figure 7A. The levees will fail, allowing water to flow across the length of each cross-section if the volume of water is sufficient to encompass the area at each section. The DNR's concept (Figure 7B) confines the floodwater to the levees at cross-sections 16, 14, and 13. Water at stages greater than levee height overflows and possibly moves into storage or drains east to the Fox River watershed. Because of the confine-

Figure 7A: Corps of Engineers Flow Concept



(from EIS, 1974)

Figure 7B: DNR Flow Concept



(from EIS, 1974)

ment of flow near Portage, the DNR's hydraulic setting is the more streamlined in the middle reaches. Flow will not occur across the total lengths of each cross-section, because of the cut-offs at the levees and the streamlined flow situation below the levees.

Three flood discharges are examined under three different conditions: the "natural state" that existed before the construction of the power plant, the present situation with the Columbia plant encroachment, and the legal condition which considers double encroachment (the requirement to consider the effects of an identical project on the other side of the river). A comparison of computer output for the first two conditions enables one to determine the velocity increases and the decreases in the amount of discharge conveyed on the east floodplain as a result of the power plant's encroachment (Table 3).

The velocity values for the present condition at cross-section 8 are the data needed to investigate the scour potential. The HEC-2 output contains the mean velocities expected to exist in the sedge meadow and along the face of the west dike (Table 4). Cross-section 8 contains 41 horizontal ground points and elevations. The first ground point, at horizontal station zero, is the left end point of the cross-section as one looks downstream. The top of the west dike is located at the 487.68 m horizontal ground point, and the east side of the North Knoll is located near the 690.60 m ground point. Velocity values that exist be-

Table 3: Velocity Increases and Conveyed Discharge Decreases Near West Dike Attributable to Encroachment of Columbia Power Plant.

Corps of Engineers Hydraulic Setting

	2-yr.	10-yr.	100-yr.		2-yr.	10-yr.	100-yr.
Cross-section 8							
*QLOB natural	251.23	594.75	1027.31	**$\bar{v}$ natural	.18	.25	.31
QLOB present	210.56	474.16	810.83	$\bar{v}$ present	.20	.27	.34
Difference	-40.67	-120.59	-216.48		+.02	+.02	+.03
Cross-section 7							
QLOB natural	624.41	1214.93	1919.61	$\bar{v}$ natural	.17	.19	.22
QLOB present	589.91	1121.02	1755.81	$\bar{v}$ present	.20	.23	.27
	-34.23	-93.91	-163.80		+.03	+.04	+.05
Cross-section 6.5							
QLOB natural	107.87	299.60	564.11	$\bar{v}$ natural	.07	.09	.12
QLOB present	93.51	235.59	419.90	$\bar{v}$ present	.08	.11	.13
	-14.36	-64.01	-144.21		+.01	+.02	+.01

*QLOB is discharge in m^3/s in left overbank (east floodplain).
**$\bar{v}$ is mean velocity in m/s on east floodplain.

DNR Hydraulic Setting

	2-yr.	10-yr.	100-yr.		2-yr.	10-yr.	100-yr.
Cross-section 8							
QLOB natural	249.92	595.06	1034.05	$\bar{v}$ natural	.19	.25	.31
QLOB present	213.11	477.22	813.95	$\bar{v}$ present	.20	.28	.34
	-36.81	-117.84	-220.10		+.01	+.03	+.03

Table 3: continued

DNR Hydraulic Setting

	2-yr.	10-yr.	100-yr.		2-yr.	10-yr.	100-yr.
Cross-section 7							
QLOB natural	618.74	1193.12	1879.74	$\bar{v}$ natural	.18	.20	.23
QLOB present	594.41	1125.30	1759.72	$\bar{v}$ present	.20	.23	.27
Difference	-24.33	- 67.82	-120.02		+.02	+.03	+.04
Cross-section 6.5							
QLOB natural	55.88	132.71	229.62	$\bar{v}$ natural	.09	.12	.16
QLOB present	55.88	132.71	229.62	$\bar{v}$ present	.09	.12	.16
	------	------	------		---	---	---

Table 4: Velocities and Percent Total Discharge Conveyed Within Specific Ground Points at Cross-sections Near Columbia Power Plant.

DNR SETTING

$Q = 979.9\ m^3/s$ (2-year flood)

Cross-sections	Ground-points (m)	Natural v(m/s)	Natural %Q	Present v(m/s)	Present %Q
8	142.0- 487.7	.15	4.9	--	--
	487.7- 666.9	.18	3.9	.18	4.1
	666.9- 777.5	.18	3.1	.21	3.3
7	304.8- 670.6	.12	3.5	--	--
	670.6- 914.4	.15	4.5	--	--
	829.4- 975.4	--	--	.15	3.2
6.5	2194.6-2575.6	.09	5.7	.09	5.7

$Q = 1761.5\ m^3/s$ (10-year flood)

Cross-sections	Ground-points (m)	Natural v(m/s)	Natural %Q	Present v(m/s)	Present %Q
8	138.1- 304.8	.21	3.8	--	--
	304.8- 487.7	.24	5.4	--	--
	487.7- 609.6	.27	3.9	.27	4.3
	609.6- 731.5	.27	4.5	-.30	4.9
7	304.8- 487.7	.15	3.0	--	--
	487.7- 670.6	.18	3.7	--	--
	670.6- 914.4	.18	6.2	--	--
	829.4- 975.4	--	--	.21	4.4
6.5	2194.6-2575.6	.12	7.5	.12	7.5

$Q = 2690.4\ m^3/s$ (100-year flood)

Cross-sections	Ground-points (m)	Natural v(m/s)	Natural %Q	Present v(m/s)	Present %Q
8	134.4- 243.8	.30	3.1	--	--
	243.8- 487.7	.30	8.7	--	--
	487.7- 609.6	.34	4.7	.37	5.3
	609.6- 731.5	.34	5.1	.40	5.8
7	304.8- 452.3	.21	3.1	--	--
	452.3- 609.6	.21	3.7	--	--
	609.6- 914.4	.24	8.5	--	--
	829.4- 975.4	--	--	.27	5.0
6.5	2194.6-2575.6	.15	8.5	.15	8.5

Table 4: continued

CORPS OF ENGINEERS SETTING

$Q = 979.9\ m^3/s$ (2-year flood)

Cross-sections	Ground-points (m)	Natural V(m/s)	Natural %Q	Present V(m/s)	Present %Q
8	142.0- 487.7	.15	5.0	--	--
	487.7- 666.9	.18	3.9	.18	4.1
	666.9- 777.5	.18	3.1	.21	3.3
7	4.3- 548.6	.09	3.3	--	--
	548.6- 914.4	.15	6.0	--	--
	829.4- 975.4	--	--	.15	3.2
6.5	555.3-1447.8	.06	5.3	--	--
	1045.5-1447.8	--	--	.06	3.8

$Q = 1761.5\ m^3/s$ (10-year flood)

Cross-sections	Ground-points (m)	Natural V(m/s)	Natural %Q	Present V(m/s)	Present %Q
8	138.1- 304.8	.21	3.8	--	--
	304.8- 487.7	.24	5.4	--	--
	487.7- 609.6	.27	3.9	.27	4.3
	609.6- 731.5	.27	4.5	.30	4.9
7	(-)30.8- 304.8	.15	3.8	--	--
	304.8- 548.6	.15	4.0	--	--
	548.6- 914.4	.18	8.4	--	--
	829.4- 975.4	--	--	.21	4.4
6.5	320.6-1045.5	.06	4.1	--	--
	1045.5-1447.8	.09	5.5	.09	5.7

$Q = 2690.4\ m^3/s$ (100-year flood)

Cross-sections	Ground-points (m)	Natural V(m/s)	Natural %Q	Present V(m/s)	Present %Q
8	134.4- 243.8	.30	3.0	--	--
	234.8- 487.7	.30	8.6	--	--
	487.7- 609.6	.34	4.7	.37	5.3
	609.6- 731.5	.34	5.1	.40	5.8
7	(-)86.0- 182.9	.15	3.1	--	--
	182.9- 365.8	.21	3.6	--	--
	365.8- 548.6	.21	3.8	--	--
	548.6- 914.4	.21	9.4	--	--
	829.4- 975.4	--	--	.27	5.0
6.5	239.0-1045.5	.09	6.4	--	--
	1045.5-1447.8	.12	6.3	.12	6.7

tween these last two points are the mean velocities to be compared with the allowable velocities obtained with the SCS critical velocity method.

Soils

Soil samples from two distinct areas are analyzed in the present study. It must be emphasized that the soils are considered in the engineering sense, that is, any material from the surface down to bedrock is soil. The floodplain surface (a sedge meadow) near cross-section 8 contains peat, marl, and sand. The dominant surface soil in the sedge meadow is peat, averaging nearly 60 cm in depth and overlying marl and fine sand. Peat depths increase up to 3.05 m near cross-sections 7 and 6.5 and up to 1.52 m between cross-sections 8 and 8.1 (IES, 1976).

Medium and fine sands are exposed on the floodplain surface in two specific locations: the bed of a drainage channel which flows north through the sedge meadow to Duck Creek, and the center of the study area where an access road once existed and the sedge vegetation is sparse (Figure 5). The latter area contains some coarse sand and gravel (possibly remnants of the access road and associated fill materials). The sedge meadow surface soils are obviously not members of the same population; therefore, only five samples, thought to be representative of the peat and sand deposits, are analyzed (Table 5).

Table 5: Soil Sample Characteristics

Soil Sample	Per-cent Sand	Per-cent Silt	Per cent Clay	D_{75}	USDA Classification	Liquid Limit (%) (-) Expedient Method	Plastic Limit (%)	Plasticity Index (%)
A+	90.33	2.57	7.1	1-2 Ø	Sand	21.2	0	0
B+ (peat)				1-2 Ø	Peat*	112.9	0	0
C+	88.15	3.52	8.33	1-2 Ø	Sand	14.1	0	0
D+	87.53	0	12.47	1-2 Ø	Loamy Sand	17.1	0	0
E+	86.14	2.65	11.21	1-2 Ø	Loamy Sand	17.3	0	0
1#	93.15	5.26	1.59	-3 Ø	Sand	15 (19)	0	0
2#	89.11	7.43	3.46	1-2 Ø	Sand	21.2 (30.1)	0	0
3#	92.34	5.01	2.65	0-1 Ø	Sand	19.3 (2.8)**	0	0
4#	89.21	6.47	4.32	1-2 Ø	Sand	19.7 (28.4)	0	0
5#	86.23	8.44	5.33	1-2 Ø	Sand	20.8 (29.5)	0	0
6#	87.79	6.34	5.87	1-2 Ø	Sand	15.3 (19.3)	0	0
7#	86.42	9.24	4.34	1-2 Ø	Sand	23.6 (25.4)	0	0
8#	85.91	7.74	6.35	1-2 Ø	Sand	21.9 (31.8)	0	0
9#	87.77	5.93	6.3	1-2 Ø	Sand	18.3 (23.2)	0	0
10#	88.16	5.75	6.09	1-2 Ø	Sand	20.1 (24.9)	0	0
11#	92.05	3.0	4.95	1-2 Ø	Sand	17.1 (20.6)	0	0
12#	90.82	5.11	4.07	1-2 Ø	Sand	18.1 (26.0)	0	0
13#	90.25	5.27	4.48	0-1 Ø	Sand	20.4 (19.8)	0	0
14#	90.36	4.53	5.11	0-1 Ø	Sand	15.4 (17.0)	0	0
15#	89.7	6.47	3.83	1-2 Ø	Sand	19.2 (20.7)	0	0
16#	88.0	6.07	5.93	-2 Ø	Sand	14.7 (16.4)	0	0
17#	89.66	5.23	5.11	0-1 Ø	Sand	17.9 (16.9)	0	0
18#	86.59	8.19	5.22	1-2 Ø	Sand	18.4 (27.2)	0	0
19#	87.73	7.5	4.77	1-2 Ø	Sand	19.5 (23.6)	0	0
20#	93.16	2.57	4.27	1-2 Ø	Sand	18.3 (19.4)	0	0
21	83.66	5.03	11.31	1-2 Ø	Sand	17.3	0	0
22	87.19	4.73	7.88	-3 Ø	Sand	23	0	0
23	79.05	9.16	11.79	1-2 Ø	Sand	26.5	16.7	9.8

Table 5: continued

Soil Sample	Per-cent Sand	Per-cent Silt	Per-cent Clay	D_{75}	USDA Classifi-cation	Liquid Limit (%) (-) Expedient Method	Plastic Limit (%)	Plasticity Index (%)
24	78.52	10.74	10.74	1-2 Ø	Sand	22.8	0	0
25	70.64	18.67	10.69	1-2 Ø	Loamy Sand	30.4	20	10.4
26	92.26	4.4	3.34	-3 Ø	Sand	25.6	0	0
27	69.95	16.28	13.77	1-2 Ø	Loamy Sand	32.3	20.8	11.5
28	64.17	22.35	12.91	1-2 Ø	Loamy Sand	23.2	15.2	8.0
29	65.13	21.19	13.68	1-2 Ø	Loamy Sand	21.8	19.4	2.4
30	60.51	20.18	19.21	1-2 Ø	Loamy Sand	31.2	19.0	12.2
Avg. A,C,D,E	88.04	2.18	9.78	1-2 Ø	Sand	17.42	0	0
Avg. 1-20	89.22	6.08	4.70	1-2 Ø	Sand	18.71 (22.1)	0	0
Avg. 21-30	75.11	13.27	11.62	1-2 Ø	Loamy Sand	25.41	11.11	5.43
Avg. 1-30	84.53	8.48	6.98	1-2 Ø	Sand	20.94	3.7	1.81

*readily identifiable as peat
**suspected procedure error
+floodplain
#dike subgroup near cross-section 8

The west dike is composed of compacted fill throughout its structure (EIR, 1973). Thirty soil samples, obtained in a systematic fashion from the dike (Figure 8), are analyzed for their classification, D_{75}, and plasticity. Since the dike is composed of a homogeneous distribution of soil, representative data for the description of the west dike are obtainable.

The 30 samples from the dike and the 5 samples from the floodplain are surface samples, generally 440 cm^3 in size. Entire samples, air-dried, were used in the sieve analysis (Appendix 1) in order to eliminate bias. Only 50 grams (smaller than 0.5 mm) of each sample were used in the hydrometer analysis (Appendix 2), and approximately 30 grams (smaller than 2.0 mm) were used in the plasticity determinations (Appendix 3). Cumulative frequency curves for each sample provide a graphical presentation of the D_{75} values (at 25% on the curves) and the percentage of sand and coarser materials (at 4 phi on the curves) for each sample (Figures 9A and 9B). Plasticity index values are obtained by the determination of the liquid and plastic limits with the liquid limit device or the expedient method.

The floodplain soils are difficult to define because of the peat and marl deposits. The peat appears cohesive, as the deposits are either below, at, or slightly above the water table. Yet the peat has no measurable plasticity. The liquid limit of the peat is greater than 100%, that is, the weight of water held by a sample is greater than the

Figure 8: Dike Soil Sample Scheme

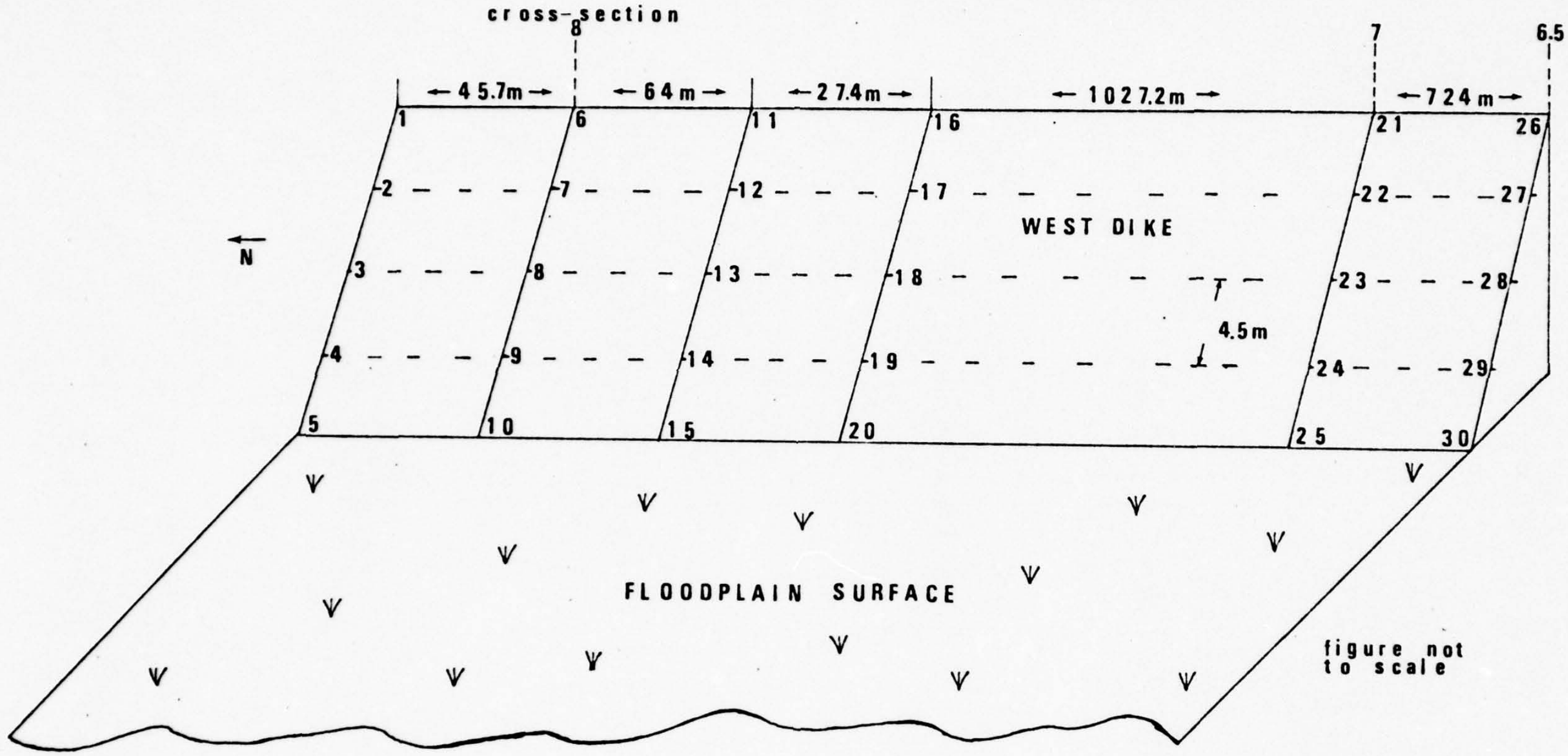


Figure 9A: Cumulative Frequency Curves for Dike Samples 1-20

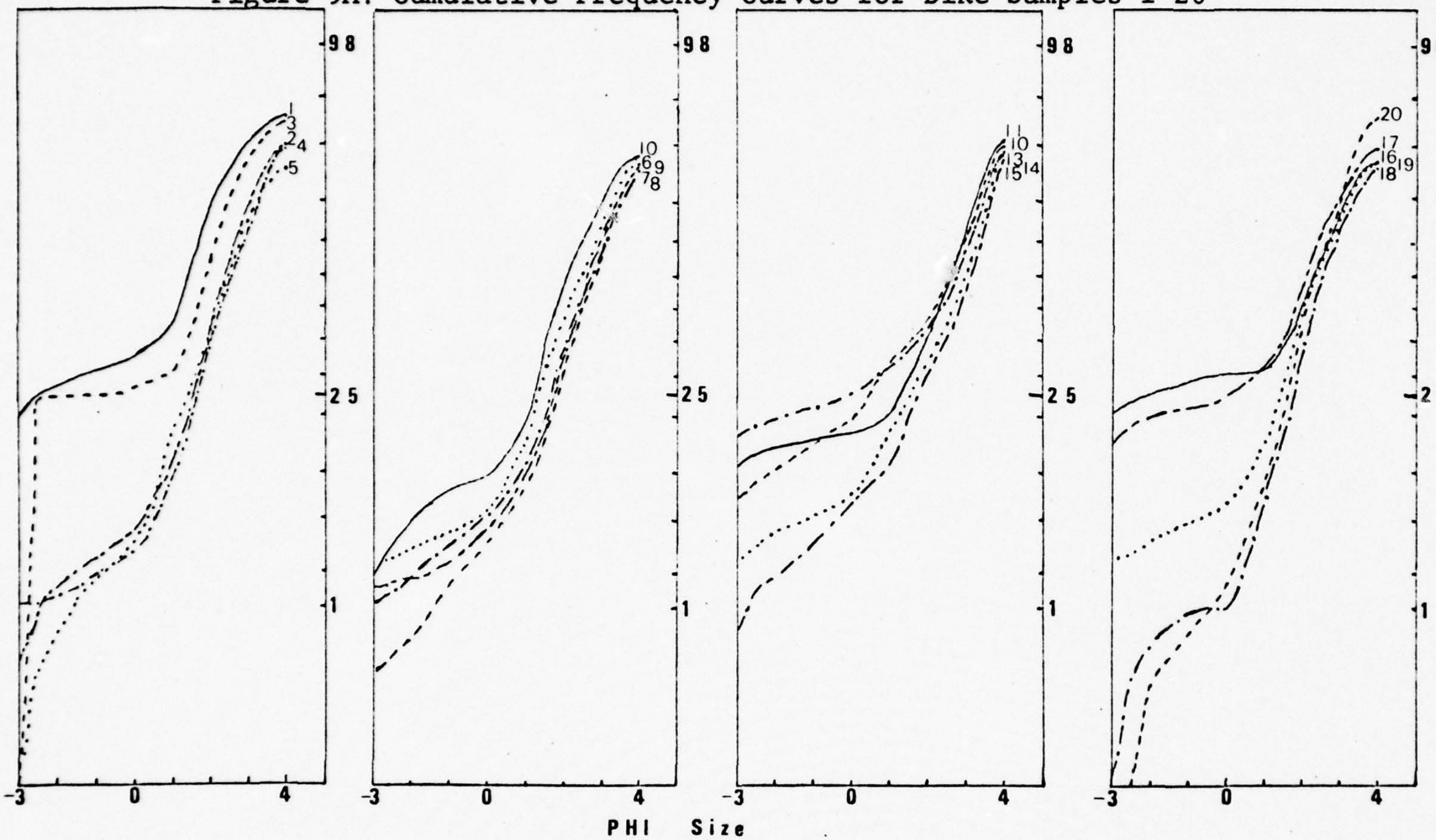
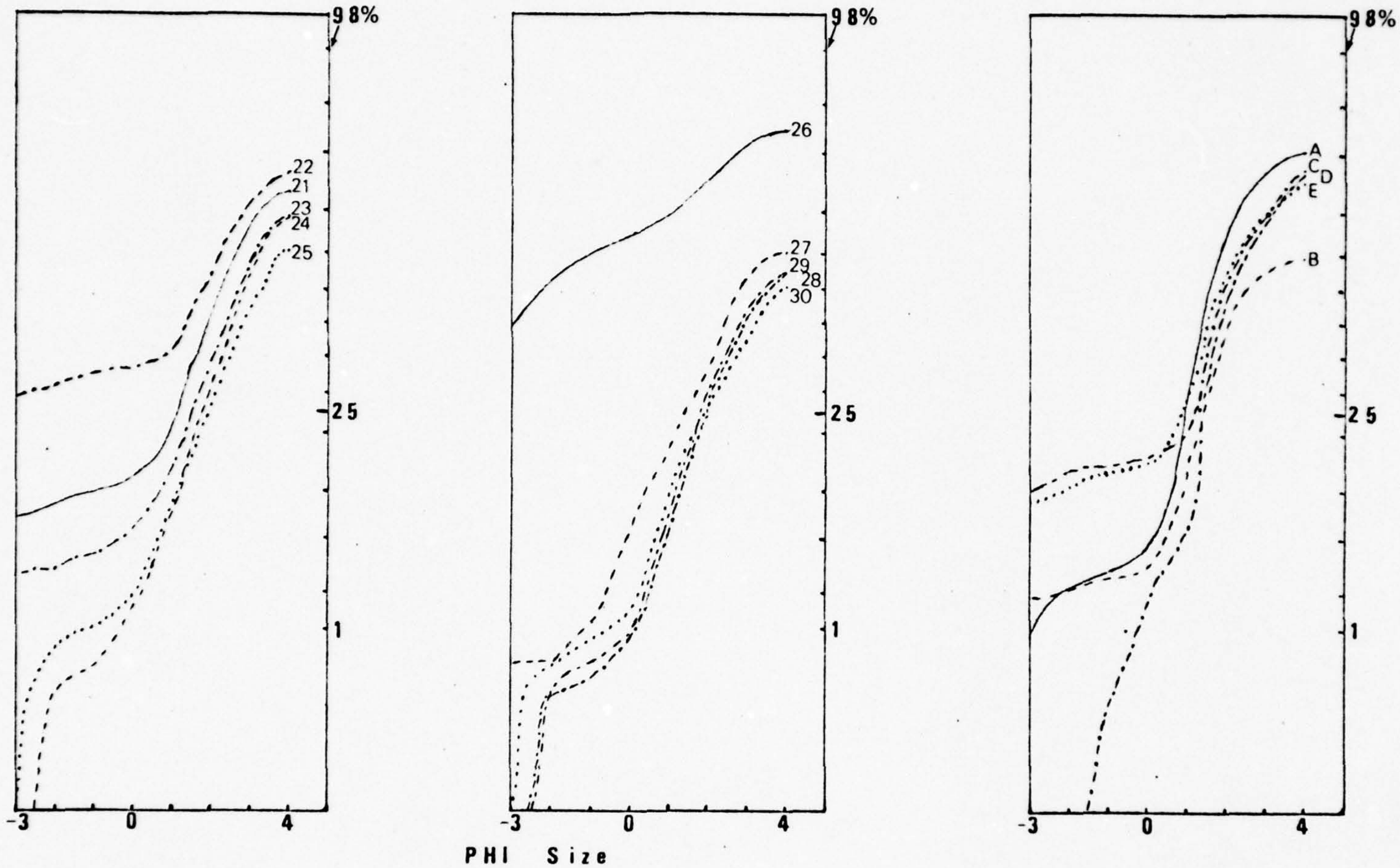


Figure 9B: Cumulative Frequency Curves for Floodplain Samples A-E and Dike Samples 21-30



weight of the peat sample itself. It appears that the peat deposits present a dilemma. According to Brady (1974), peat has low plasticity and cohesion, but does not behave as a mineral soil with the same characteristics because of the peat's fibrous structure. Peat normally has water contents much greater than 100%, in fact, peat can hold water to the extent of one to 20 times its weight. If the peat dries out, it can harden to a pan-like structure or break apart into small particles subject to wind erosion (Brady, 1974). The study area should not reach such a state because the ground water level is at the surface throughout most of the sedge meadow. This condition has been, and should continue to be, aided by the inflow of water from the cooling lake either through or under the base of the dike into the sedge meadow (IES, 1976). Thus, the peat deposits in the sedge meadow should always be wet. In such a state the peat seems to offer a high resistance to scour, even though the material has low plasticity and cohesion. Since the critical velocity method depends upon particle size (among other things), the scour potential of the peat cannot be evaluated in this research because of the peat's fibrous nature. Therefore, only the sand deposits in the drainage channel and in the center strip near cross-section 8 are considered.

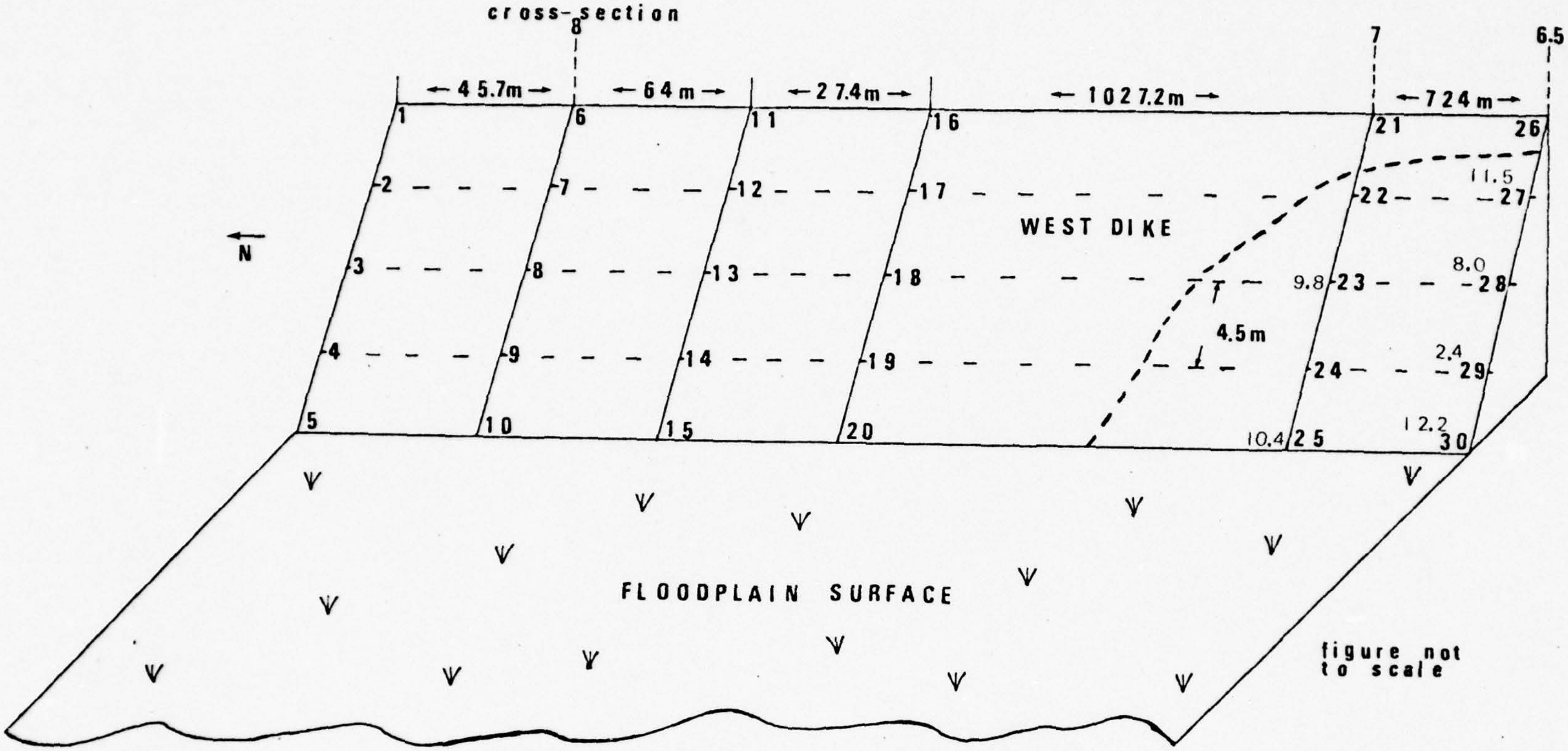
The sand deposits on the floodplain can be evaluated for their potential to scour. The four sand samples present reasonably uniform characteristics. They have average sand-silt-clay percentages of 88-2-10, which classifies

these surface soils as Sand in the United States Department of Agriculture (USDA) scheme. D_{75} values range from 1 phi to 2 phi, with 1 phi (0.5 mm) selected as the most representative size. These characteristics only describe the sand deposits in the drainage channel and the center strip. The greater area of the sedge meadow contains the rather elusive--from the viewpoint of critical velocity--peat deposits at the surface.

The dike presents a more definable situation. The 20 samples taken near cross-section 8 have average sand-silt-clay percentages of 89-6-5 and a USDA classification of Sand. Two of the samples have D_{75} values greater than 2 phi, but the remaining 18 samples have D_{75} sizes between 0 phi and 2 phi. Again, 1 phi (0.5 mm) is the most representative D_{75} value. The distribution of soil samples for the entire dike, including samples 21-25 along cross-section 7 and samples 26-30 from cross-section 6.5, has average sand-silt-clay percentages of 84.5-8.5-7.0 and a USDA classification of Sand. D_{75} values include two 3 phi and eight 1 phi sizes in the additional 10 samples. A representative size of 1 phi is selected as the D_{75} value for the entire west dike.

The plasticity of the dike soils is very low. Only samples near the base of the dike and samples from cross-sections 7 and 6.5 exhibit any measurable plastic limit (Figure 10). Liquid limits were determined for all dike and floodplain samples with the liquid limit device. The field

Figure 10: Distribution of Plasticity Indices
(indices on south end of dike in fine print)



expedient method was also used to determine liquid limits for the 20 dike samples from the vicinity of cross-section 8.

Every soil has a definite value of the liquid limit. This characteristic adds to the strength of any soil classification scheme. Sands normally have liquid limits that range between 15% and 20%. If the liquid limit is less than 35%, the soil has low plasticity. Soils with low liquid limits are softened when wetted and their strength is often reduced by only minor increases in water content. However, soil structure has to be destroyed before a soil is weakened enough to flow, even if the water content is increased up to the liquid limit (Kezdi, 1974).

The 20 dike samples taken near cross-section 8 exhibit liquid limits ranging from 14.7% to 23.6% with the liquid limit device. The range is from 16.4% to 30.1% with the expedient method. All 20 samples have liquid limit values less than 35% for either method. The surface soils on the dike near cross-section 8 exhibit low plasticity, if any. Plastic limits could not be measured for any of the 20 samples; thus, they all have plasticity indices of zero. The plasticity index is the difference between the liquid limit and the plastic limit, but soils with no plastic limit have no plasticity index either (Kezdi, 1974).

The samples taken from the dike near cross-sections 7 and 6.5 have some plasticity. In fact, 6 of 10 samples had measurable plastic limits. The plastic limits ranged from

15.2% to 20.8%, which is reasonable since very fine sands exhibit some plasticity--usually values of 17% to 20% (Kezdi, 1974). The plasticity indices for 5 of the 6 samples with plastic limits are greater than 7. Bureau of Reclamation results show a value of 7 to be a tentative critical value for canal design. Scour can result from moderate threshold forces in materials with a plasticity index below 7 (Chow, 1959).

The floodplain samples, excluding the peat sample, are rather homogeneous with average sand-silt-clay percentages of 88-2-10. They can be classified as Sand according to the USDA method. The liquid limits are from 14.1% to 21.2%, within the range expected for fine sands.

Analysis

The SCS critical velocity charts can be examined now that the expected mean velocities and the soil characteristics are known. All samples from the floodplain (peat excluded) and the dike are categorized as either silty or clayey sands with more than 5% fines (Figure 11A). Values for plasticity index (PI) exist only for 6 samples from the southern portion of the dike near cross-sections 7 and 6.5. All other samples have plasticity indices of zero. The representative value of the D_{75} is 0.5 mm (1 phi) for all samples. Grab sampling of suspended sediment during an approximate 2-year flood in March 1976 showed the flood water to be clear with no detritus.

Soil Description		PI	Velocity: Clear	Velocity: Suspen-ded	Velocity: Bed-load
Silty sands with more than 5% fines		<10	Curve 1		
		10 20	76.2		
Clayey sands with more than 5% fines		7–10	Curve 1		
		10-20	76.2		
		>20	121.9		

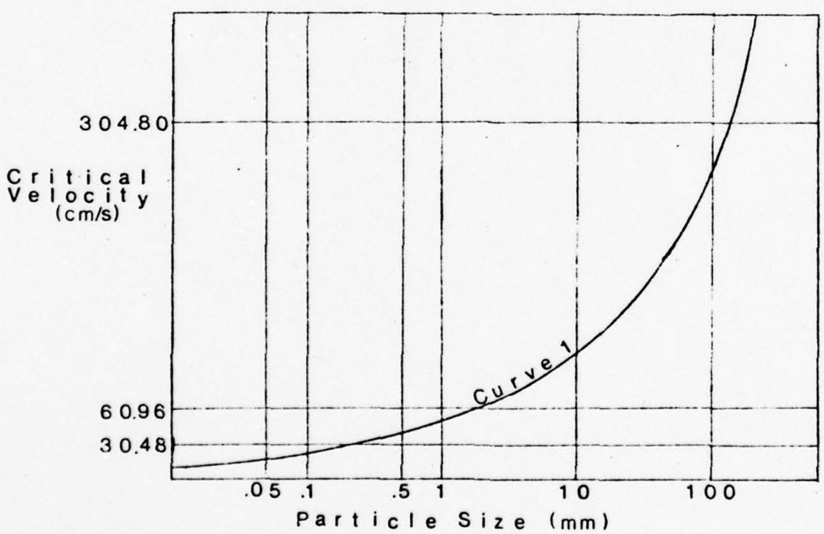


Figure 11A: SCS Critical Velocity Curves

(from SCS, 1964)

With the preceding information, it is apparent that Curve 1 of Figure 11A is used with a D_{75} value of 0.5 mm to determine the non-scouring velocity for all of the samples with no plasticity index. From the chart, a velocity of 39.6 cm/s is obtained. This value must be corrected for alignment, bank slope, and water depth (Figure 11B). Alignment and bank slope are assumed to be constant for all three discharges under consideration, whereas the depth of flow increases significantly with increasing discharge. For the west dike, a bank slope of 4:1 gives a slope angle (Z) of $\approx$ 14° with a cotangent of $\approx$ 4. Therefore, the bank slope correction factor is not applicable to either the dike or the floodplain. The alignment factor near cross-section 8 is the same (assumed so) for all discharges. The curve radius near the study area is greater than 1950.7 m and the water surface width is $\approx$ 121.9 m. The width of the water surface actually does change with discharge, but the resultant change in the alignment factor (curve radius/water surface width) is insignificant. Depth of flow for the different floods is approximate because an assumption, that the flood channel near cross-section 8 is rectangular, is made. This assumption is valid considering the small contribution of the knoll and dike side-slopes to the total area.

The water depths for the three discharges are:

	area (m^2)	width (m)	depth (m)
2-year flood	147.31 (147.54)	121.92 (121.92)	1.21 (1.21)
10-year flood	268.19 (267.39)	121.92 (121.92)	2.20 (2.19)
100-year flood	385.79 (383.88)	121.92 (121.92)	3.16 (3.15)

NOTE: DNR setting values are followed by Corps of En-

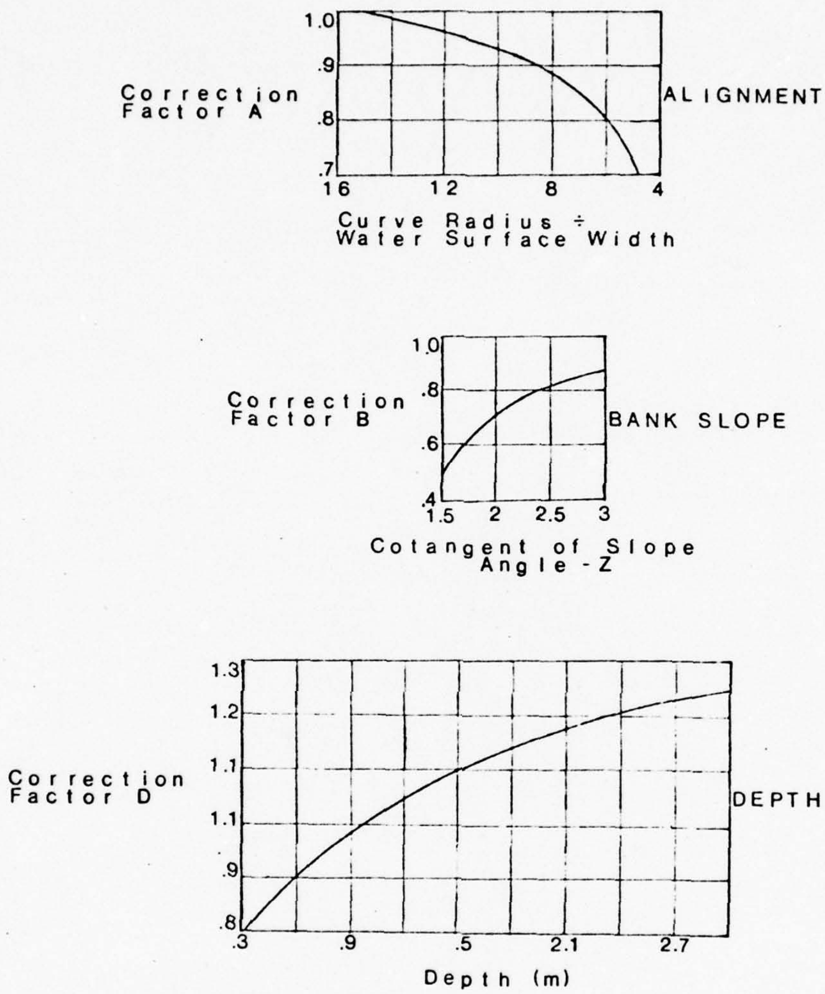


Figure 11B: SCS Critical Velocity Correction Factors

(from SCS, 1964)

gineers setting values in parantheses.

The flood channel near cross-section 8 is slightly sinuous. Map analysis and personal observations during a 2-year flood lead to this conclusion. It is possible that the less frequent events could destroy the sinuosity because of the greatly increased depths and volumes of water. However, for the purposes of this research, the sinuosity is assumed to remain constant for all events under consideration.

With the data heretofore presented, the maximum permissible velocities that can exist before scour should occur are:

	chart value	x	A	x	B	x	D		
2-year flood	39.6	x	1	x	.9	x	1.05	=	37.5 cm/s
10-year flood	39.6	x	1	x	.9	x	1.18	=	42.1 cm/s
100-year flood	39.6	x	1	x	.9	x	1.25	=	44.5 cm/s

However, these velocities, as determined by the SCS method, are not sacrosanct. The agency is wary of conclusions based upon allowable velocities of less than 61 cm/s. Personal communication with two SCS engineers could provide no adequate reasons as to why the method used in the present research should not be valid (Brown, 1976; Kamper, 1976). In order to get another view of the problem, the critical velocity method based upon Russian data is employed (Chow, 1959). If the D_{75} grain size value is used with the Chow method (Figure 12), the same allowable velocities are obtained as with the SCS method. This fact is not surprising though, since the SCS method is partly based upon the same

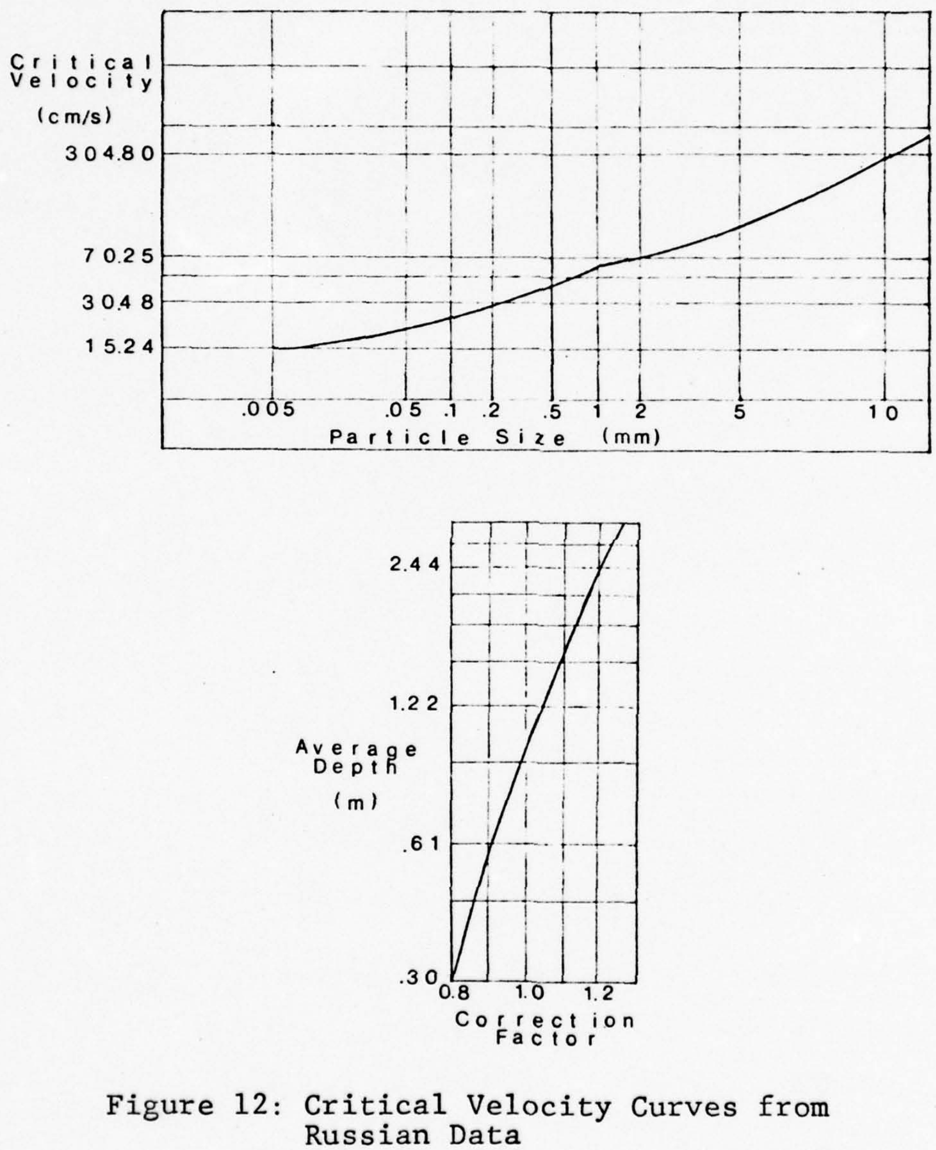


Figure 12: Critical Velocity Curves from Russian Data

(from Chow, 1959)

Russian data. If the average grain size (D_{50} = 0.25 mm or 2 phi) is used, different velocities are obtained:

TABLE 6: Expected Velocities and Critical Velocities

	Expected V (HEC-2)	Critical V (Chow)	Critical V (SCS)
2-year flood	18.3 cm/s	32 cm/s	37.5 cm/s
10-year flood	27.4 cm/s	36 cm/s	42.1 cm/s
100-year flood	36.6 cm/s	38.1 cm/s	44.5 cm/s

Although both critical velocity methods are based upon empirical results, this researcher is confident that the critical velocities obtained, the SCS values and the lower limit figures from the method described by Chow, are reasonable. The critical velocity curve of Hjulström (1935) cannot be used for comparison because it is based upon uniform, monodispersed material.

There appears to be little doubt that the smaller two floods do not have the velocities required to scour the west dike and the sands on the floodplain in the vicinity of cross-section 8, no matter what allowable velocity is considered. The 100-year event is not so clear-cut, however. The difference between the expected velocity and the allowable velocity obtained with the Chow data is too small to discount the possibility of scour.

If complete faith could be placed in the SCS allowable velocities, then it would be safe to say that scour would not occur, even during the 100-year event. But the doubts about the SCS method for the lower velocities, combined with the results of the analysis with the Russian data, require that the conclusion to this part of the hypothesis test re-

mains uncertain. Thus, scour could possibly occur during the 100-year flood.

What about the expected velocity values? They are obtained from the HEC-2 analysis, which relies upon the currently accepted discharge values for each recurrence interval. If the climate has changed toward a wetter and cooler regime since about 1950, it is possible that the discharge values used in the HEC-2 analysis are too low, which would mean that the expected velocities are probably too low as well. Before these matters are explored, the backwater hypothesis must be tested with the same data used above in the scour analysis.

CHAPTER V

THE BACKWATER HYPOTHESIS: DATA AND ANALYSIS

Backwater is an important consideration in any large development project on a river floodplain. Limitations often exist as to how much backwater can be created by a new construction. A 15.24 cm limit exists in Wisconsin for the amount of increase in water surface height permitted near urban areas. Previous maximum values for the backwater effect resulting from the Columbia Generating Station ranged from 7.9 cm (Corps of Engineers) to 15.54 cm (Thomas Lee of DNR).

The backwater question at Portage is significant for a number of reasons: (1) the Columbia Site Impact Study Group wants to know which figures are correct, and why, because their research objectives include the requirement for a thorough understanding of all factors to be considered in the siting of future power plants, (2) the possibility exists that enough backwater is created to significantly alter the expected stage-discharge relationship and, thus, affect the expected capability for flood control of the Portage levees, and (3) the need exists to know the contribution of this project to the water surface heights at Portage so that it can be accounted for when new developments are to take place in the vicinity of the study area.

The results of the backwater investigation (Tables 7A and 7B) are not as dramatic as expected. Both hydraulic

Table 7A

Backwater Data: Corps of Engineers Setting

Flood	Cross-Section	Water Surface Elevations (m) Natural	Present	Double Enc.	Backwater (cm)
100-year 2690.4 m^3/s	8	241.15	241.18	241.20	5.18
	8.1	241.19	241.24	241.26	6.40
	9	241.29	241.33	241.35	5.79
	9.1	241.32	241.36	241.37	5.79
	10	241.39	241.43	241.44	5.18
	10.33	241.43	241.47	241.48	5.18
	11	241.50	241.54	241.55	4.88
	12	241.60	241.63	241.65	4.57
	13	241.53	241.57	241.58	4.88
	14	242.37	242.38	242.39	1.83
	16	242.89	242.89	242.90	0.91
10-year 1761.5 m^3/s	8	240.21	240.23	240.24	3.35
	8.1	240.25	240.28	240.29	4.27
	9	240.36	240.38	240.39	3.35
	9.1	240.39	240.40	240.47	2.74
	10	240.51	240.48	240.49	----
	10.33	240.55	240.51	240.53	----
	11	240.63	240.60	240.61	----
	12	240.74	240.71	240.72	----
	13	240.45	240.40	240.41	----
	14	242.25	242.25	242.25	----
	16	242.83	242.83	242.83	----

Table 7A: continued

Flood	Cross-Section	Water Surface Elevations (m) Natural	Present	Double Enc.	Backwater (cm)
2-year $979.9\ m^3/s$	8	239.20	239.20	239.21	1.22
	8.1	239.23	239.24	239.25	1.83
	9	239.37	239.37	239.37	0.90
	9.1	239.40	239.39	239.40	0.30
	10	239.53	239.48	239.49	----
	10.33	239.57	239.52	239.53	----
	11	239.66	239.62	239.62	----
	12	239.81	239.78	239.78	----
	13	240.22	240.22	240.22	----
	14	242.29	242.29	242.29	----
	16	242.85	242.85	242.85	----

NOTE: All Figures Converted from English Units and Rounded Off to the Nearest Hundredth.

Table 7B

Backwater Data: DNR Setting

Flood	Cross-Section	Water Surface Elevations (m) Natural	Present (Double Enc.)	Backwater (cm)
100-year $2690.4\ m^3/s$	8	241.18	241.20	2.13
	8.1	241.22	241.26	3.66
	9	241.33	241.37	3.35
	9.1	241.39	241.42	3.05
	10	241.56	241.59	2.74
	10.33	241.62	241.65	2.74
	11	241.81	241.83	2.44
	12	242.08	242.10	1.83
	13	242.21	242.22	1.52
	14	242.73	242.74	0.91
	16	243.18	243.18	0.61
10-year $1761.5\ m^3/s$	8	240.21	240.23	2.13
	8.1	240.25	240.28	3.05
	9	240.38	240.40	2.74
	9.1	240.43	240.45	2.44
	10	240.60	240.62	2.13
	10.33	240.66	240.68	1.83
	11	240.85	240.86	1.52
	12	241.13	241.14	1.22
	13	241.26	241.27	0.91
	14	241.76	241.76	0.61
	16	242.28	242.28	0.30

Table 7B: continued

Flood	Cross-Section	Water Surface Elevation (m) Natural	Water Surface Elevation (m) Present (Double Enc.)	Backwater (cm)
2-year $979.9\ m^3/s$	8	239.19	239.23	4.27
	8.1	239.22	239.24	1.83
	9	239.37	239.39	1.22
	10	239.42	239.43	1.22
	10.33	239.66	239.66	0.91
	11	239.83	239.84	0.91
	12	240.13	240.14	0.61
	13	240.26	240.27	0.61
	14	240.75	240.75	0.30
	16	241.29	241.29	----

NOTE: All Figures Converted from English Units and Rounded Off to the Nearest Hundredth.

settings (those of the DNR and the Corps of Engineers) provide maximum water surface elevation increases far less than the 15.24 cm calculated by Mr. Lee. In fact, the maximum value, 6.4 cm during the 100-year flood at cross-section 8.1 in the Corps of Engineers setting, is less than the maximum value espoused by the Corps during the 1972 environmental impact proceedings.

The reason for the large discrepancy between the results of the present study and those of the earlier studies stems from the interpretation of what double encroachment is. Under the law, double encroachment means that an amount of conveyance equal to that lost on one side of a river because of an encroachment must be subtracted from the other side of the river. In other words, construction which is identical to that proposed must be assumed to exist opposite the proposed plant on the other side of the river. The backwater which would result from the encroachment of both plants is that which must be considered to satisfy the terms of double encroachment (Schmied, 1973). Most state ordinances, including that of Wisconsin, consider double encroachment only for the 100-year (regional) flood.

Results of this study depict the magnitude of the expected backwater effect for three floods and two different hydraulic settings. For the DNR setting, double encroachment is accounted for in the study's analysis of the "Present" situation (Table 7B). The significant findings are two: the magnitude of the possible backwater effect is far less

than that determined by Mr. Lee or any of the previous researchers, and the greatest effect of the backwater occurs near the power plant, as the effect of the backwater is greatly diminished near Portage itself.

From the data available, it seems that the encroachment of the Columbia plant creates a lesser impact than originally thought. The ability of the river to spread out across its floodplain during flood events probably accounts for the results to a great extent. The small, if existent, backwater values for cross-sections 16, 14, and 13 near Portage suggest a rejection of the hypothesis that the encroachment of the Columbia plant may affect the Wisconsin-Fox River drainage situation during floods of modest recurrence intervals.

Finally, it seems that the plant's effect during the regional flood is well within the limits established by the DNR floodplain zoning ordinance. The reason for the large discrepancy between the results of this study and others involves the interpretation of double enroachment. Only the area directly across the river from the Columbia plant was considered in the double encroachment procedure in the present study. Earlier research done by Mr. Lee considered double encroachment from the power plant upstream to the city of Portage. The interpretation of the ordinance made in the present study is believed to be the intent of the law.

The 6.4 cm water surface elevation increase at cross-section 8.1 (C of E setting) is a substantial increase, even if it falls within allowable limits. Whether this increase has any geomorphic significance is questionable, however.

It is of interest to consider how the backwater effect may, in fact, be of substantial importance if indiscriminate floodplain development occurs. Multiple developments compound the backwater effect, possibly to such an extent that any limits are greatly exceeded because of the combined effects of more than one project. The possibility of such an occurrence in the study area appears to be minimal because the floodplain ordinance is shown to be much more effective than originally thought.

CHAPTER VI

THE CLIMATE CHANGE HYPOTHESIS: DATA AND ANALYSIS

A change to a cold and wet climate regime could have a significant effect on flood magnitude and frequency, and thus on geomorphic analyses of the type presented in this research. Today's climate in the Upper Wisconsin River Valley may be similar to that of the cold, wet meridional climatic regime that existed prior to 1895.

1873-1910 DATA

The first step in the test of the climate change hypothesis is an examination of rainfall and streamflow data for the period 1873-1910 in order to detect the change in precipitation regimes thought to have occurred in 1895, and also to determine the precipitation characteristics of a meridional regime.

Monthly rainfall data are grouped into the three hydrologic seasons. Graphs of precipitation versus time (Figure 13) depict a noticeable difference in precipitation values between the first and second halves of the period in each of the three seasons. The time series show that a shift from a wetter to a drier regime occurred in the mid-1880s.

Running means are simple ways to show the existence of a change in climate and the presence of a trend in climatic data. The 5-year (Figure 14) and 10-year (Figure 15) running means depict a significant change in climate from a

Figure 13: Precipitation and Fall Low Flows 1873-1910

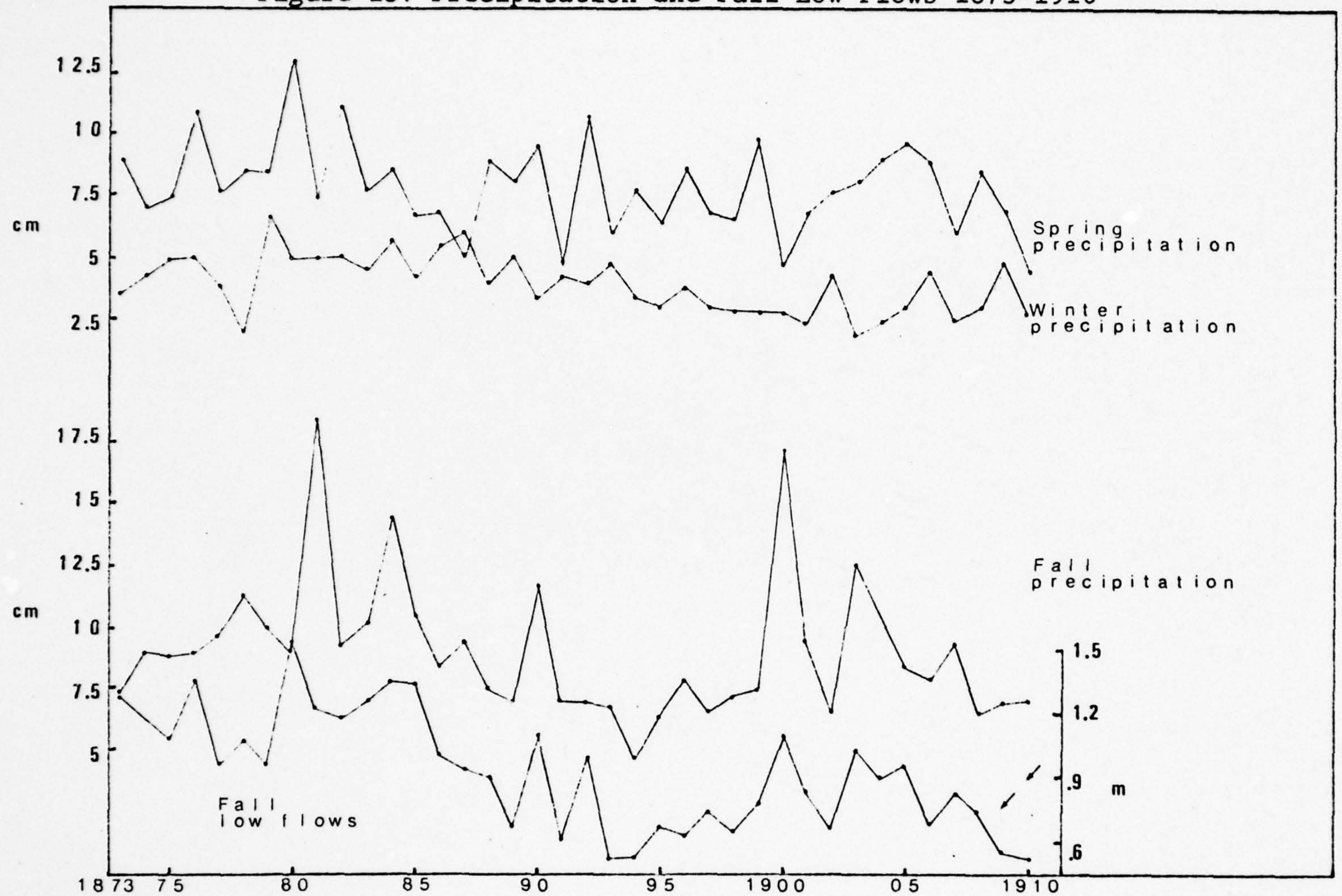


Figure 14: 5-year Running Means 1873-1910 Precipitation and Fall Low Flows

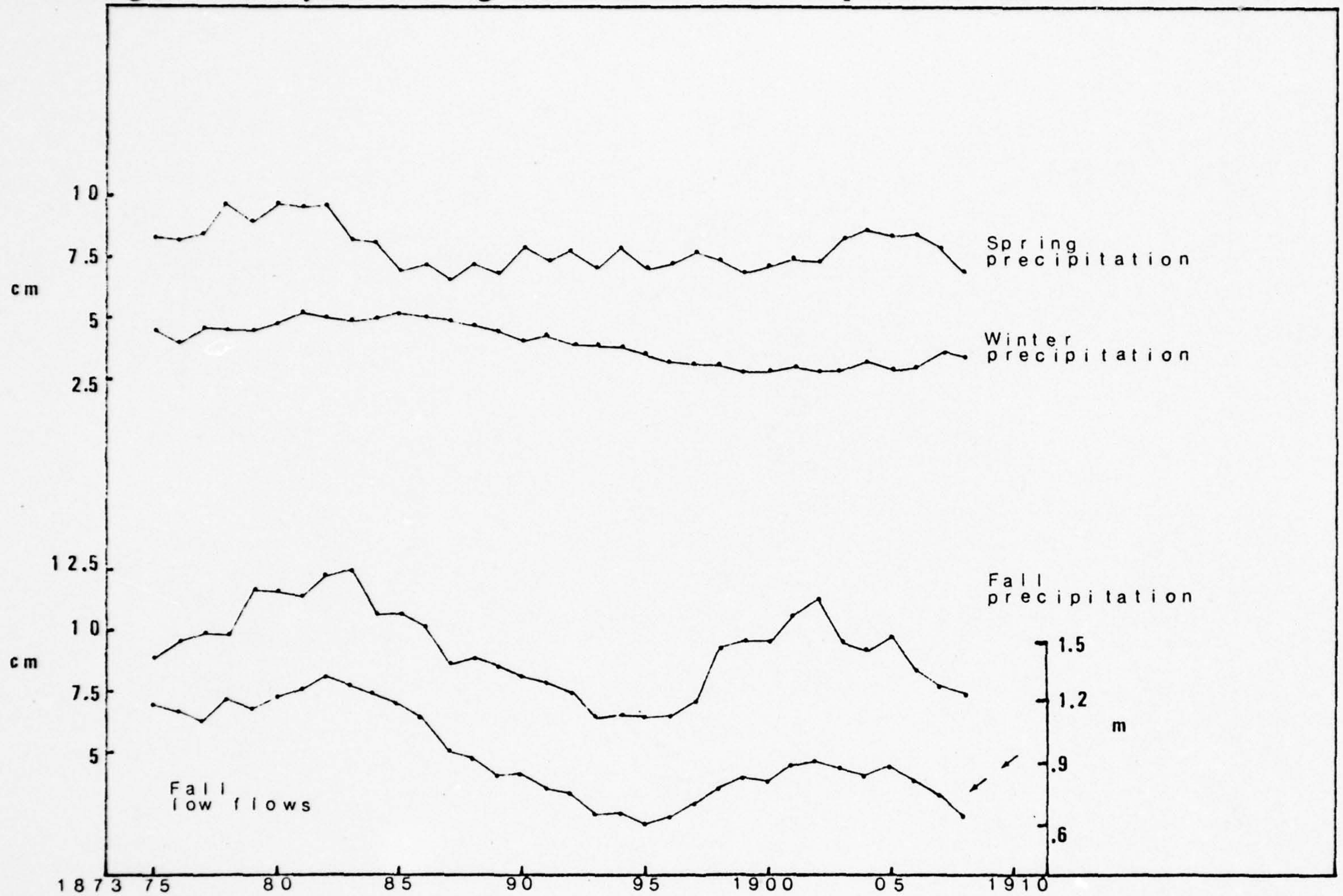
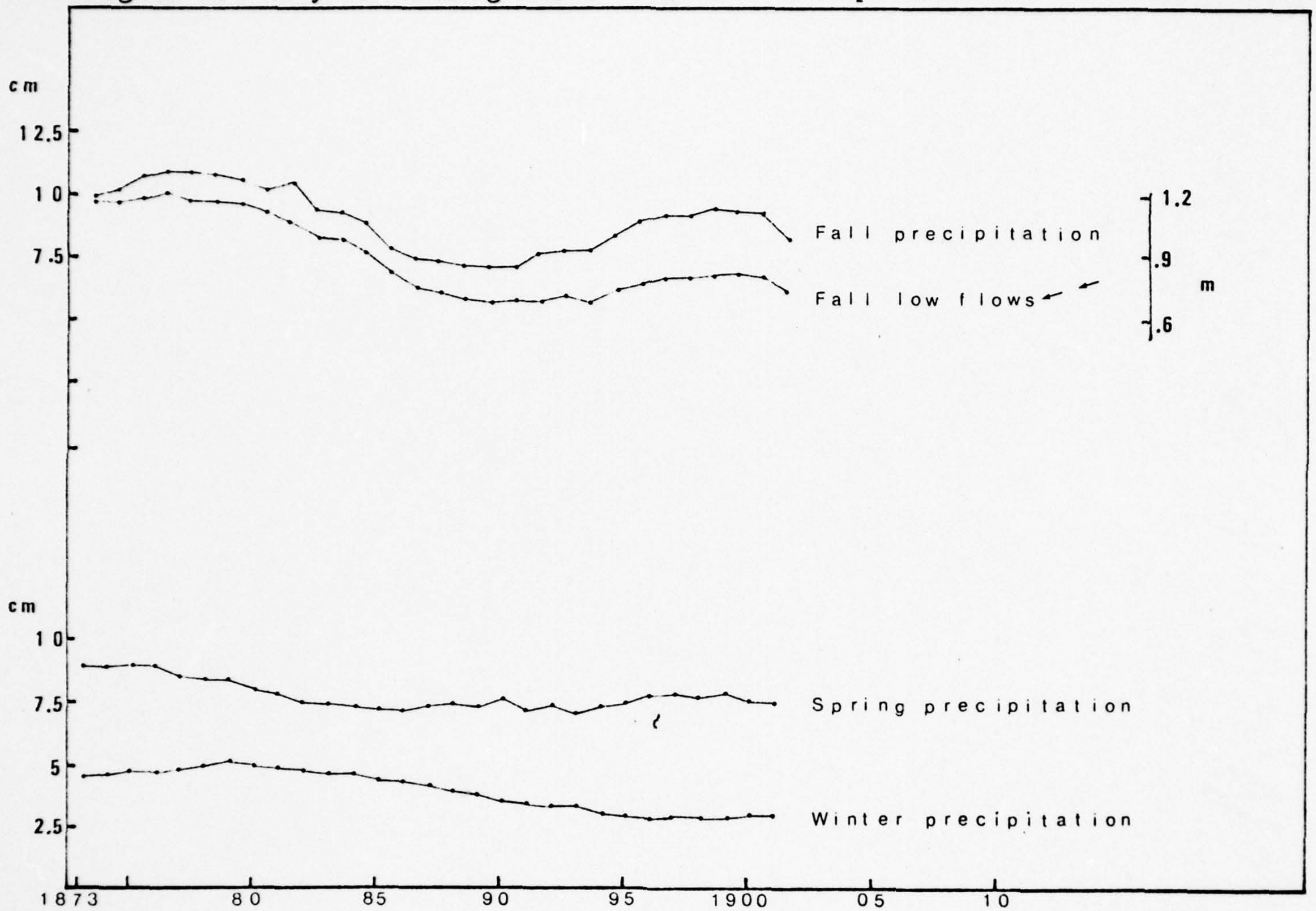


Figure 15: 10-year Running Means 1873-1910 Precipitation and Fall Low Flows



wetter to a drier regime in each hydrologic season (.001 > P for Fall and Winter and .01 > P for Spring). The change appears to have taken place around 1885 in all seasons. Graphs depicting cumulative deviations from the mean (Figure 16) effectively show the time when the change occurred. The year 1885 appears to be the time of change for the Spring and Fall hydrologic seasons, but the evidence points to 1890 as the year that the climate changed to a drier regime in the Winter season.

Streamflow data for the 1873-1910 interval are limited to low flows for the Fall hydrologic season. Low flows are appropriate because they should accurately reflect the degree of wetness or dryness of the prevailing climate. Low flows can be employed because the Wisconsin River was not regulated to any extent during the 1873-1910 period. Unfortunately, low flow data for only the Fall season are available. Too many low flow data are missing from the record to use the low flow variable for the Spring and Winter seasons. However, the Fall is a season of great significance because most of the high-magnitude flood events on the Wisconsin River have occurred during that season (C of E, 1971).

Low flows for the Fall are presented in the same fashion as the precipitation data. Graphs of low flows versus time (Figure 13), 5-year and 10-year running means (Figures 14 and 15), and cumulative deviations from the mean (Figure 17) are employed in the analysis. Graphically, Fall low flows correspond quite well with Fall precipitation data

Figure 16: Cumulative Deviations from the Mean 1873-1910 Precipitation

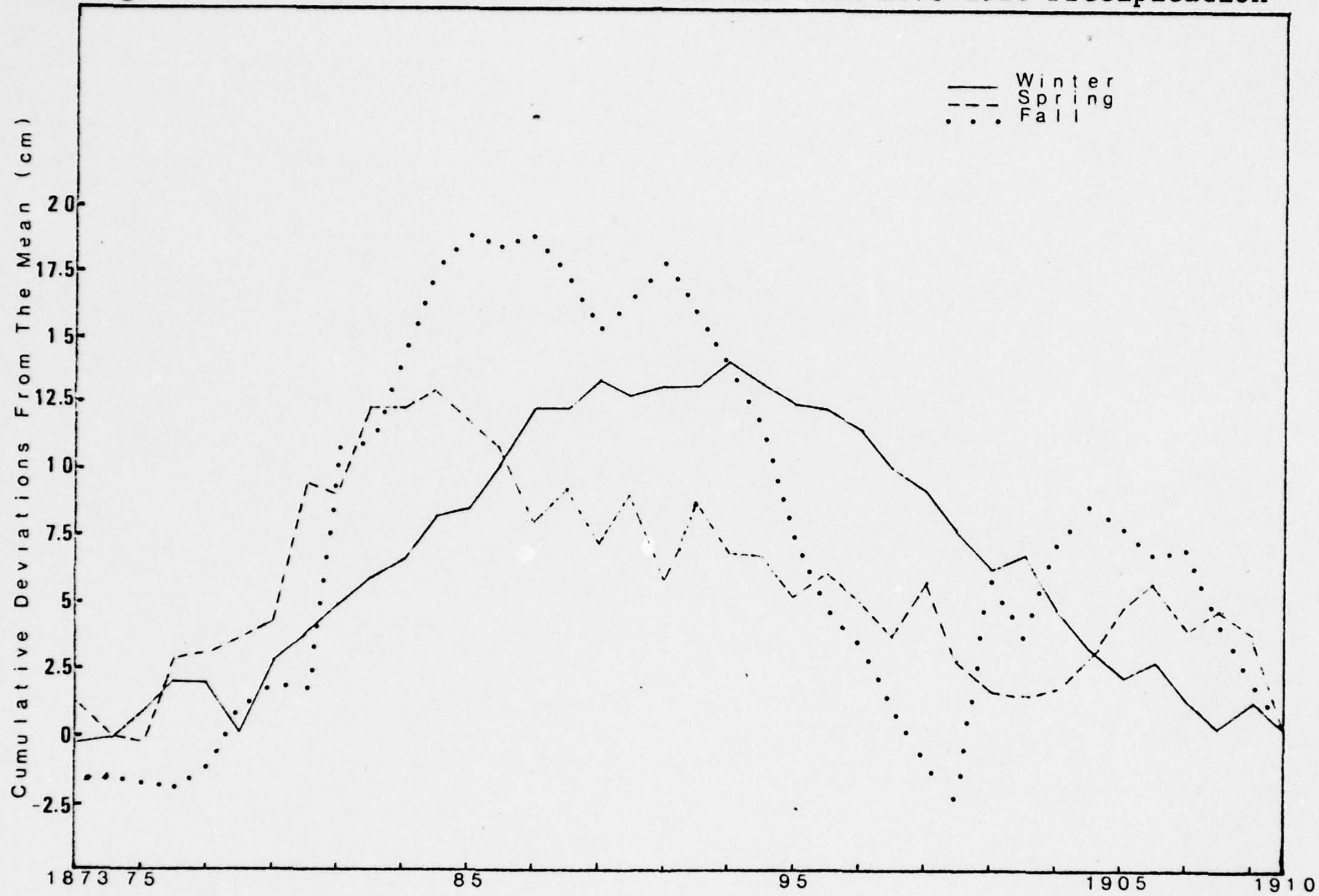
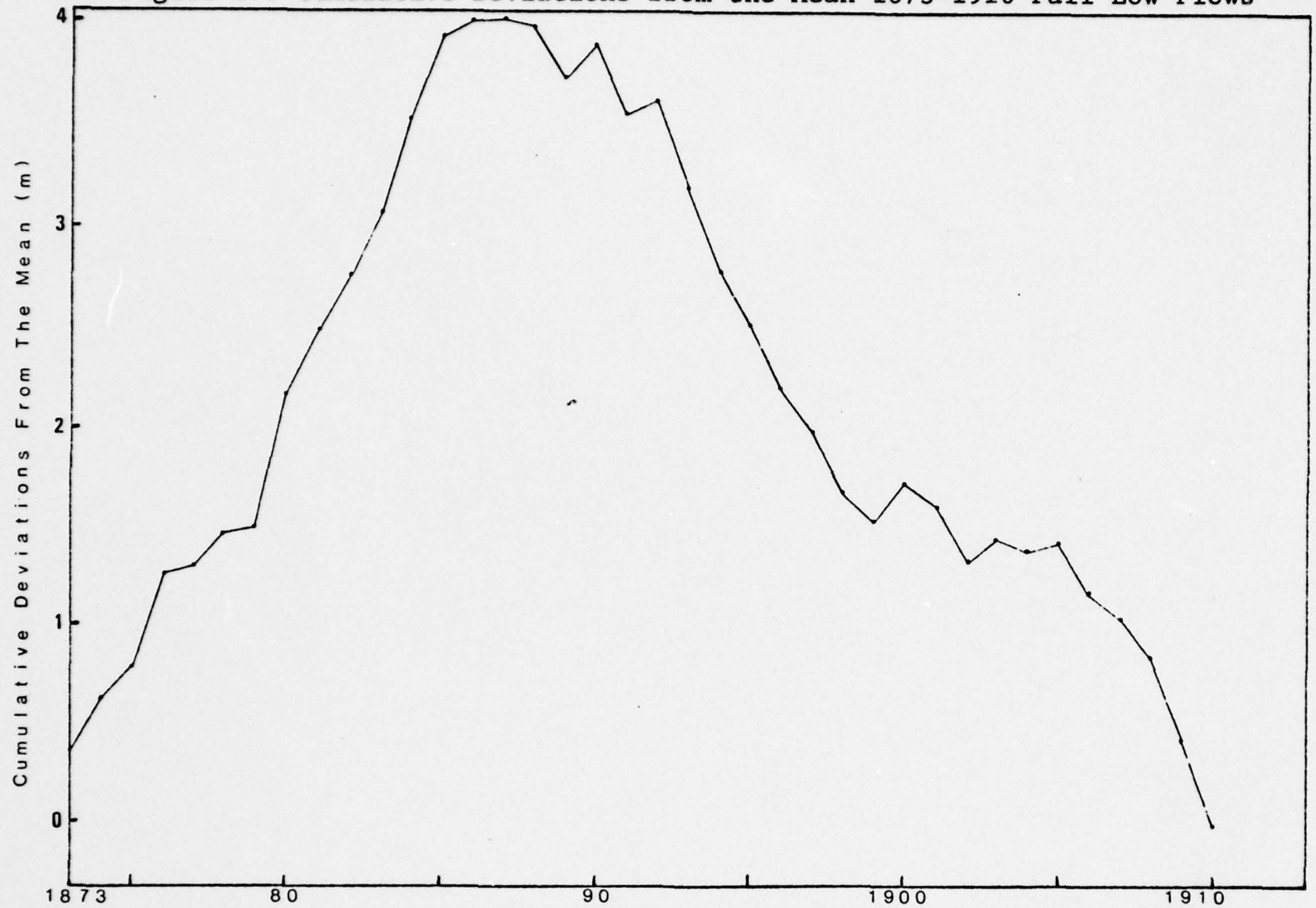


Figure 17: Cumulative Deviations from the Mean 1873-1910 Fall Low Flows



(Figure 13), although a regression analysis produced an R^2 of only +0.35, .001 > P. A graph of cumulative deviations from the mean (Figure 17) clearly shows the change in 1885 from a wetter to a drier regime.

Although the data do not reflect a change in climate in 1895 as proposed, they do clearly portray the existence of a change in regime, beginning in 1885 for the Spring and Fall seasons but not until 1890 for the Winter. The meridional regime is much wetter than the zonal regime that succeeded it. Persistence of variability, a characteristic of meridional circulation (Knox et al., 1975), is most noticeable during the pre-1885 time of meridional circulation in the Spring season. The Spring meridional regime has highly variable precipitation values, all above the mean. However, the Spring variability remains persistent throughout the entire period of record, although the later values are not as great as the pre-1885 precipitation totals. Persistence of variability is not as marked in the other seasons, as there are successions of years with persistent wetness or dryness and no evident persistence of variability. Thus, from the rainfall and streamflow data, the following inferences can be drawn: (1) that a shift in climate, from a wetter to a drier regime, did occur; (2) that the change in climate took place around 1885, rather than 1895; (3) that the pre-1885 regime, the meridional circulation regime, is characterized by amounts of precipitation in all three hydrologic seasons greater than the totals for the zonal post-1885 period; and

(4) that persistence of variability, as a characteristic of a meridional regime, appears to be less significant than the increased amounts of precipitation.

1925-1975 DATA

Lamb (1966) and others hypothesized that the upper air circulation patterns in the northern hemisphere shifted from a zonal back to a predominantly meridional regime around 1950. Precipitation and streamflow data from the period 1925-1975 are analyzed in order to test for the proposed change in climatic regime. The hypothesized meridional regime should resemble the meridional regime that existed in the Upper Wisconsin River Valley prior to 1885. This being so, the new regime should have greater than average precipitation values and significant persistence of variability, the latter characteristic at least in the Spring.

Precipitation data from 13 weather stations upstream of the Columbia Generating Station (Table 1) are used in the analysis. The data are grouped in the three hydrologic seasons. As with the precipitation data from the 1873-1910 period, these data are also refined through the use of time series (Figure 18A, B, and C), cumulative deviations from the mean (Figure 19), and 5-year and 10-year running means (Figures 20 and 21).

An examination of the graphs of precipitation versus time for each hydrologic season reveals no conclusive evidence of a shift in precipitation patterns in each season.

Figure 18A: Spring Precipitation and Streamflow 1925-1975

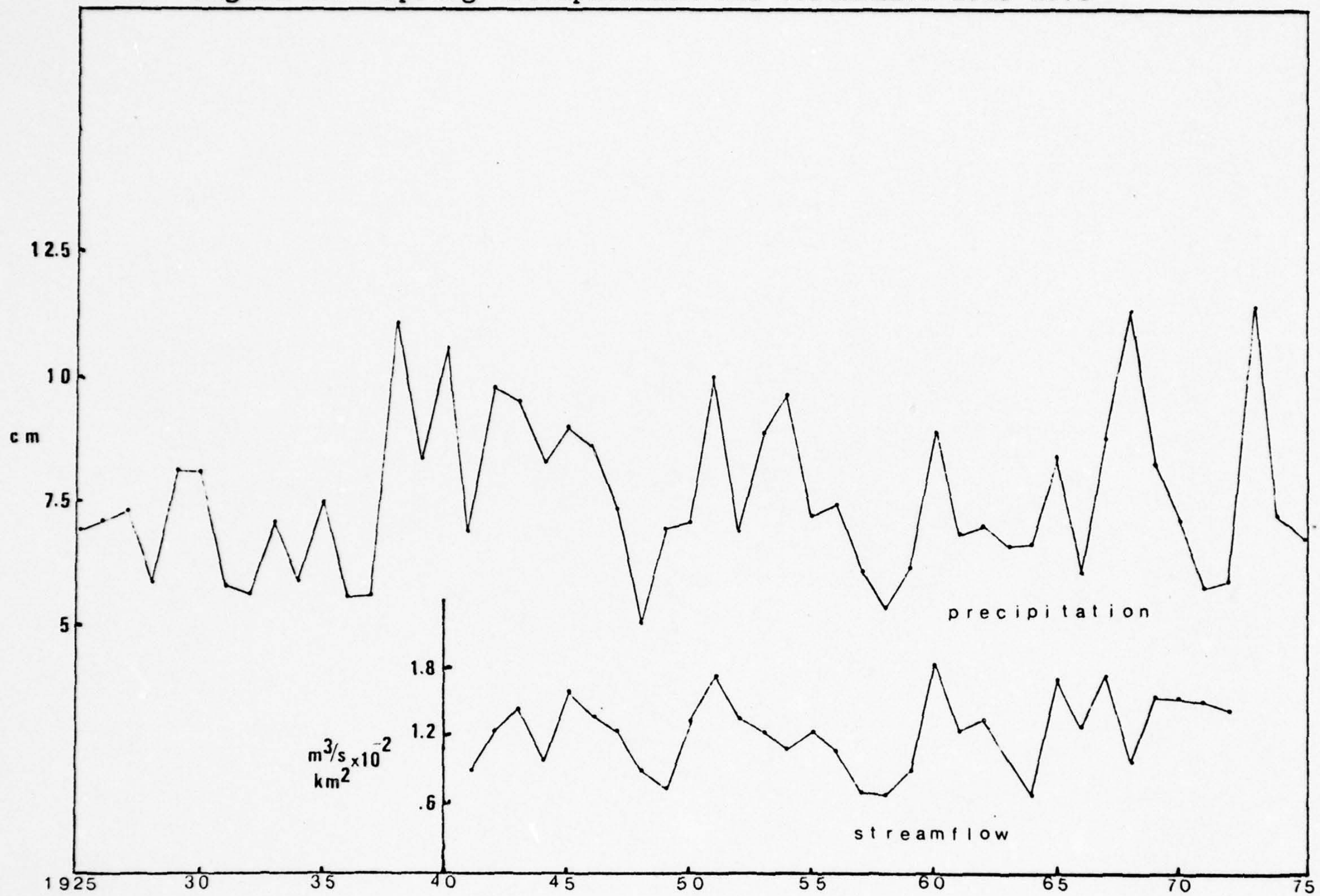


Figure 18B: Fall Precipitation and Streamflow 1925-1975

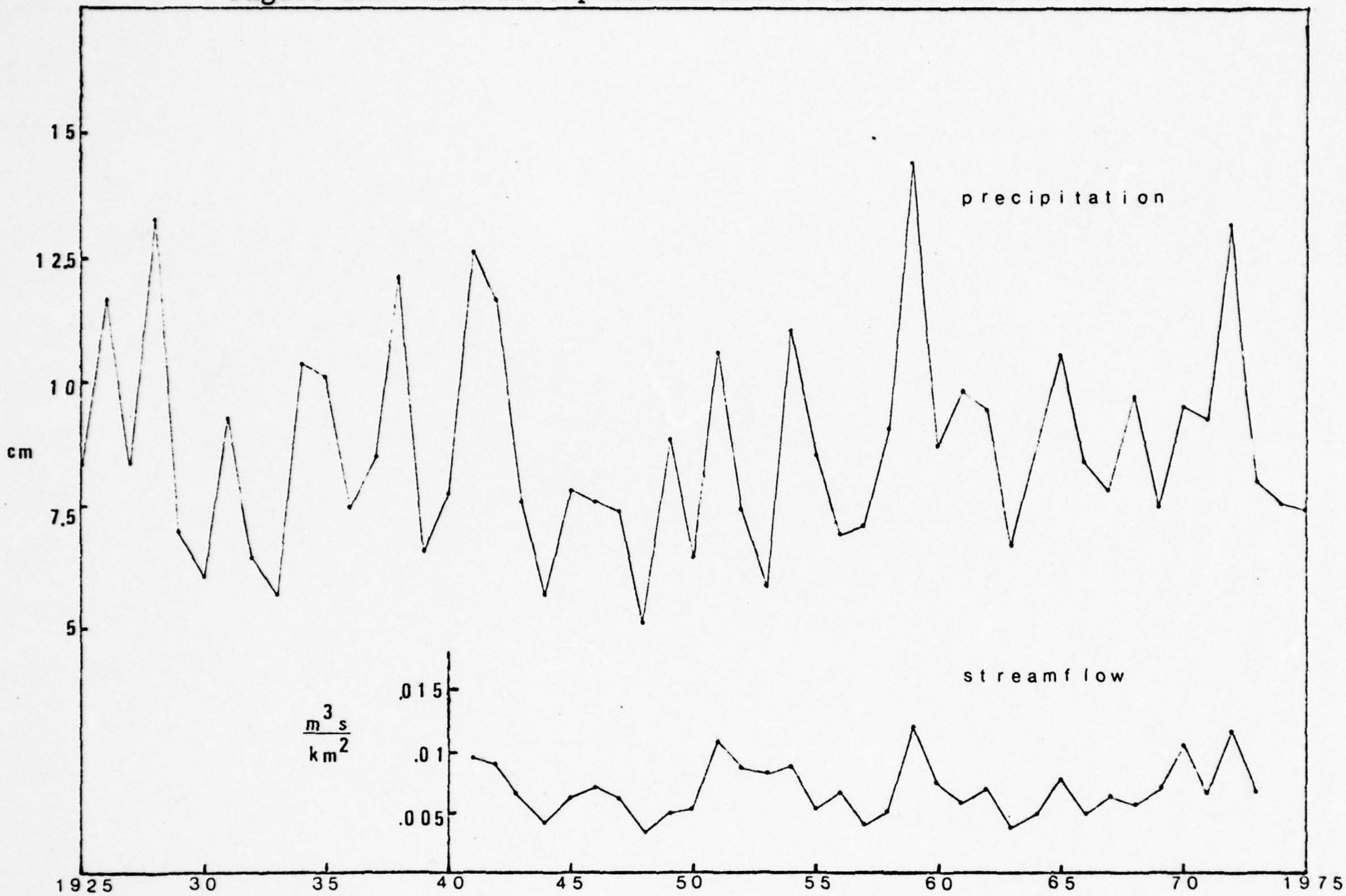


Figure 18C: Winter Precipitation and Streamflow 1925-1975

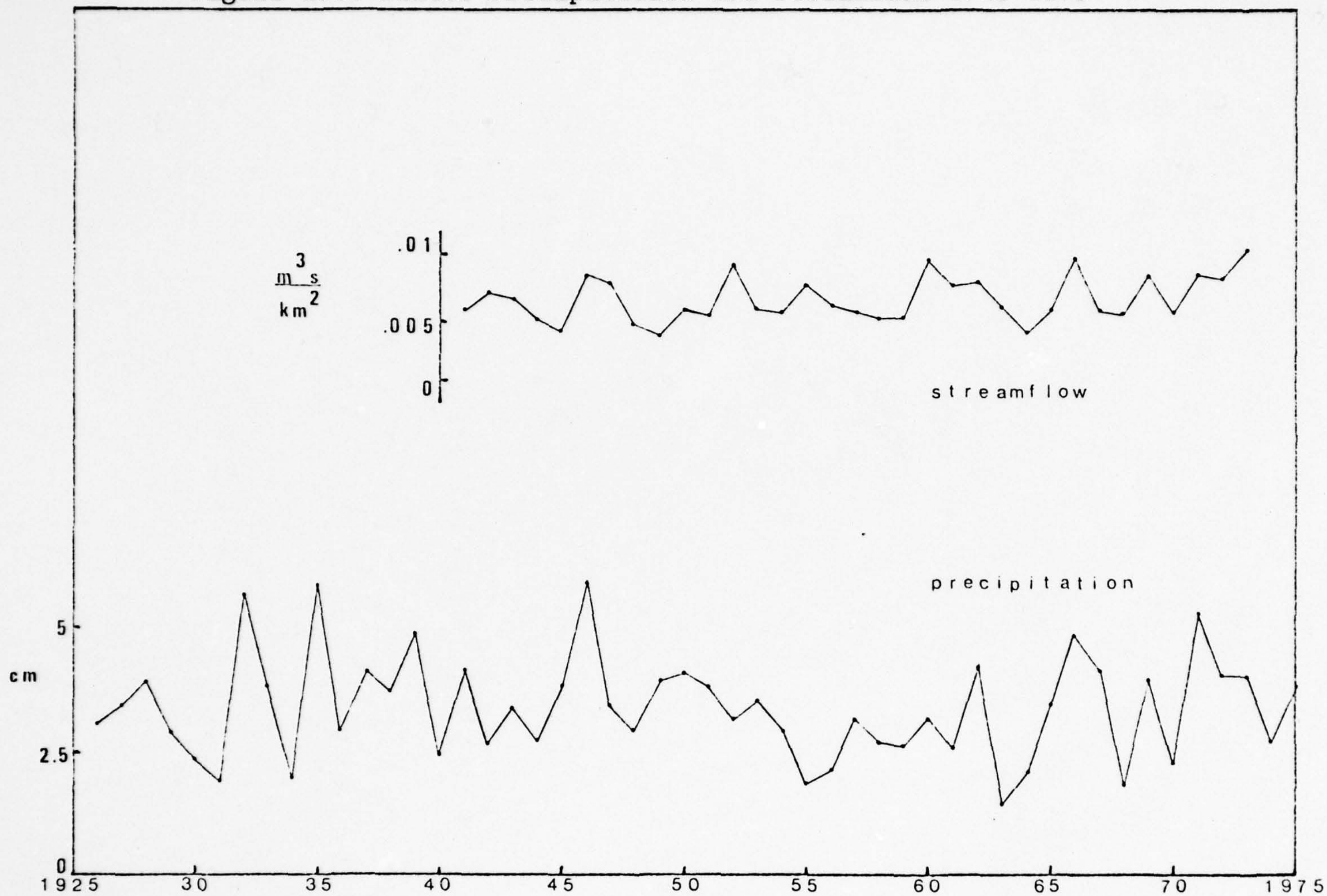
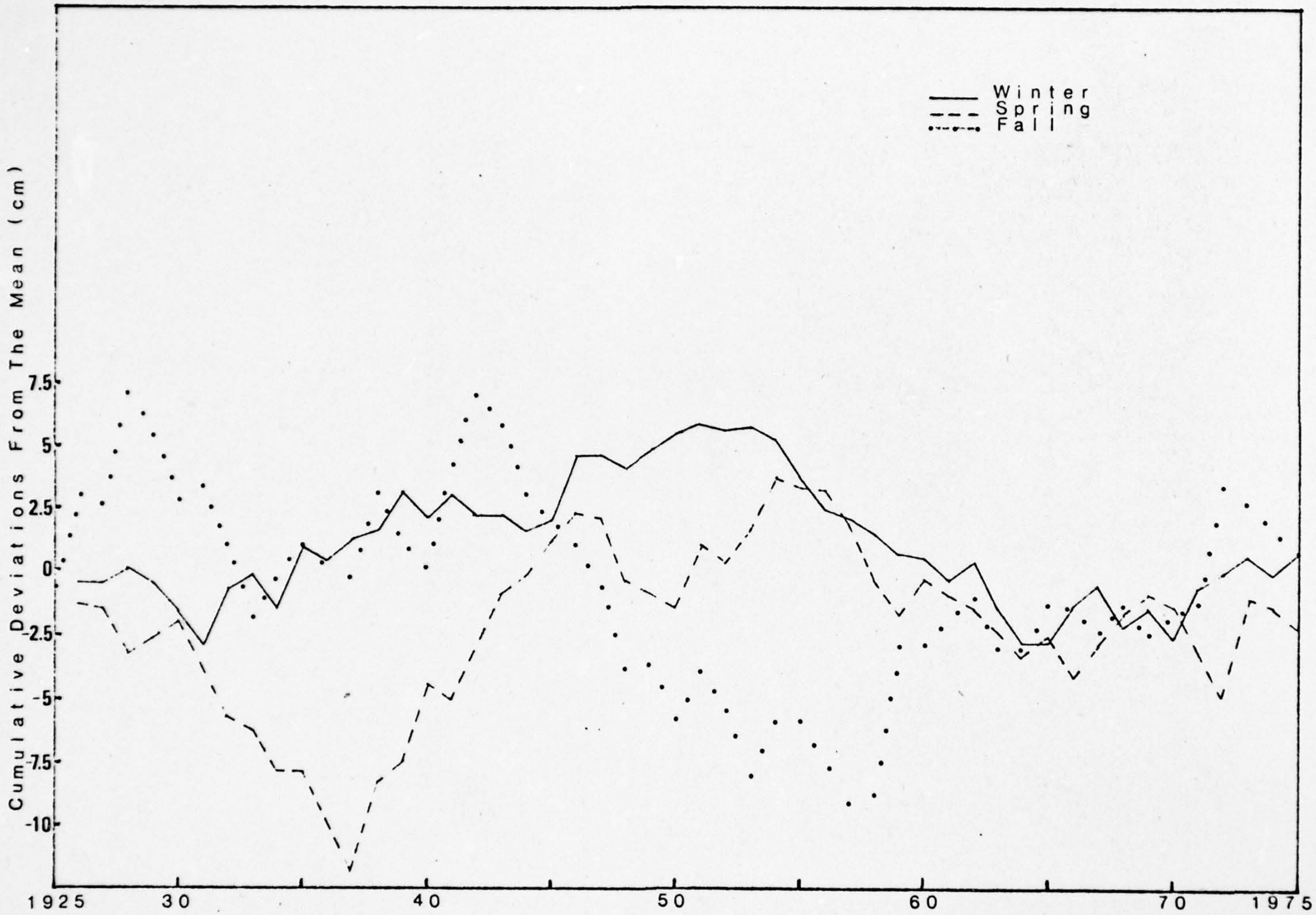


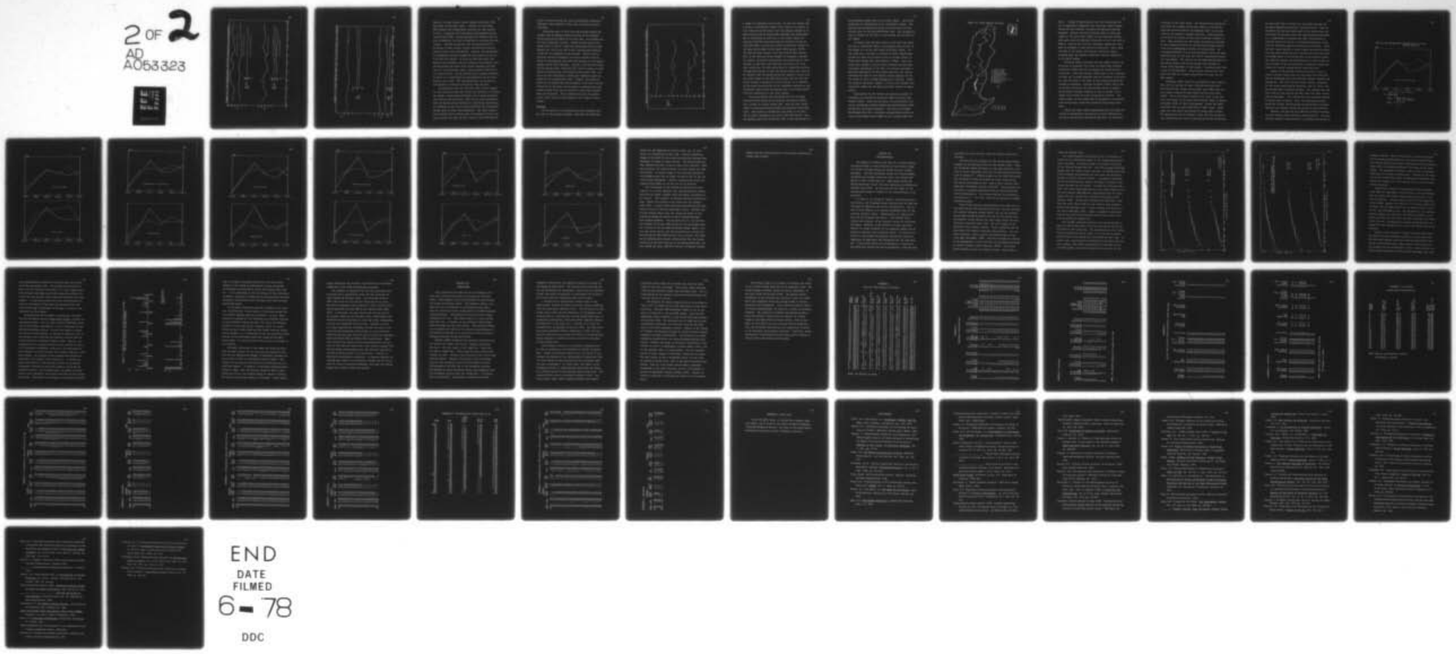
Figure 19: Cumulative Deviations from the Mean 1925-1975 Rainfall



AD-A053 323 WISCONSIN UNIV-MADISON DEPT OF GEOGRAPHY F/G 8/8
GEOMORPHIC IMPLICATIONS OF FLOODPLAIN ENCROACHMENT NEAR PORTAGE--ETC(U)
1977 D H MADIGAN

UNCLASSIFIED NL

2 OF 2
AD
A053323



END
DATE
FILMED
6-78
DDC

Figure 20: 5-year Running Means 1925-1975 Precipitation and Streamflow

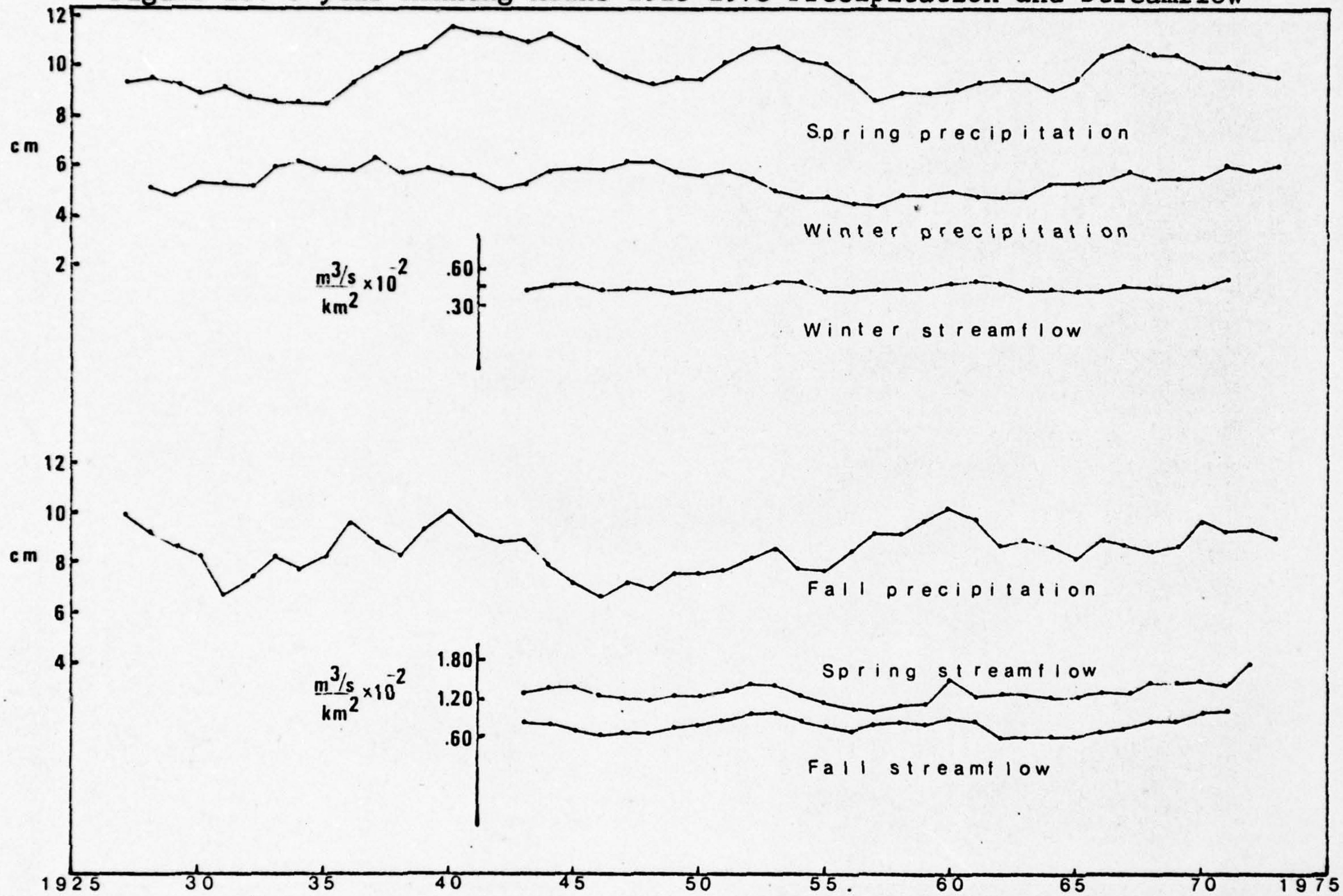
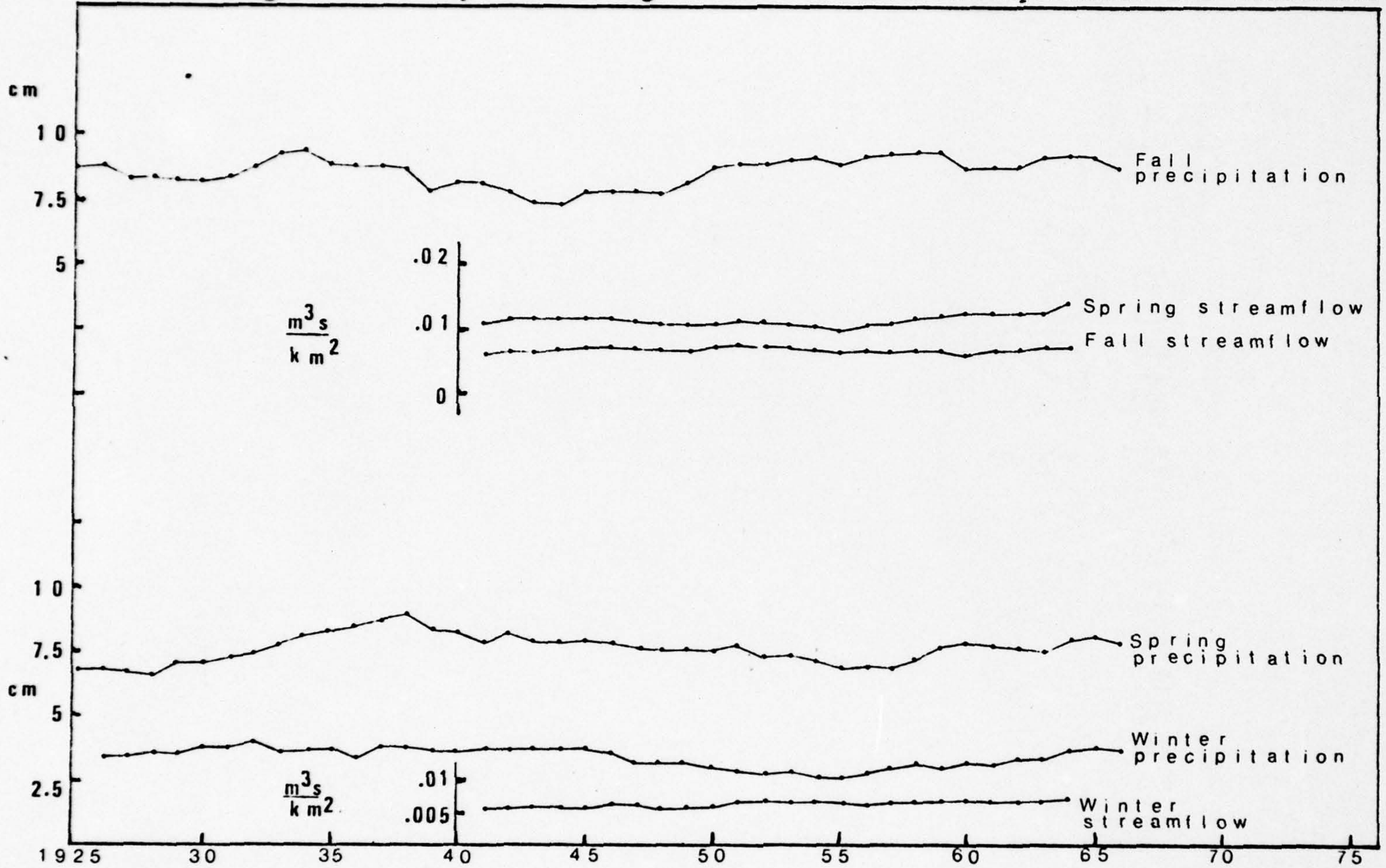


Figure 21: 10-year Running Means 1925-1975 Precipitation and Streamflow



However, a trend toward a wetter regime since about 1950 does exist in the Fall season. Analysis of the graphs which depict the running means produces the same results. In fact, it appears as if the Winter precipitation has decreased since 1950. Spring precipitation exhibits year-to-year variability, but this variability is certainly not persistent. The Fall season has both characteristics of a meridional climate regime: greater precipitation and persistent year-to-year variability. However, the persistence of variability carries through the Fall season for the entire 1925-1975 period. As with the 1873-1910 data, the Spring season exhibits the best evidence of persistent variability during the years which should encompass the dominance of the meridional regime, approximately 1950-1975 in the recent period. Winter precipitation is again anomalous, as there is a trend toward low precipitation and low variability since 1950. The same information can be gleaned from graphs of cumulative deviations from the mean.

Precipitation data for 1925-1975 offer little support for the hypothesis that the climate has shifted to a meridional regime, characterized by higher than average precipitation amounts and persistent, high year-to-year variability. Only the Spring season exhibits any significant persistence of variability that can be dissociated from the variability during times of zonal flow domination. All three seasons were markedly wetter during times of meridional flow in the early period, but only the Fall season in the 1925-1975 in-

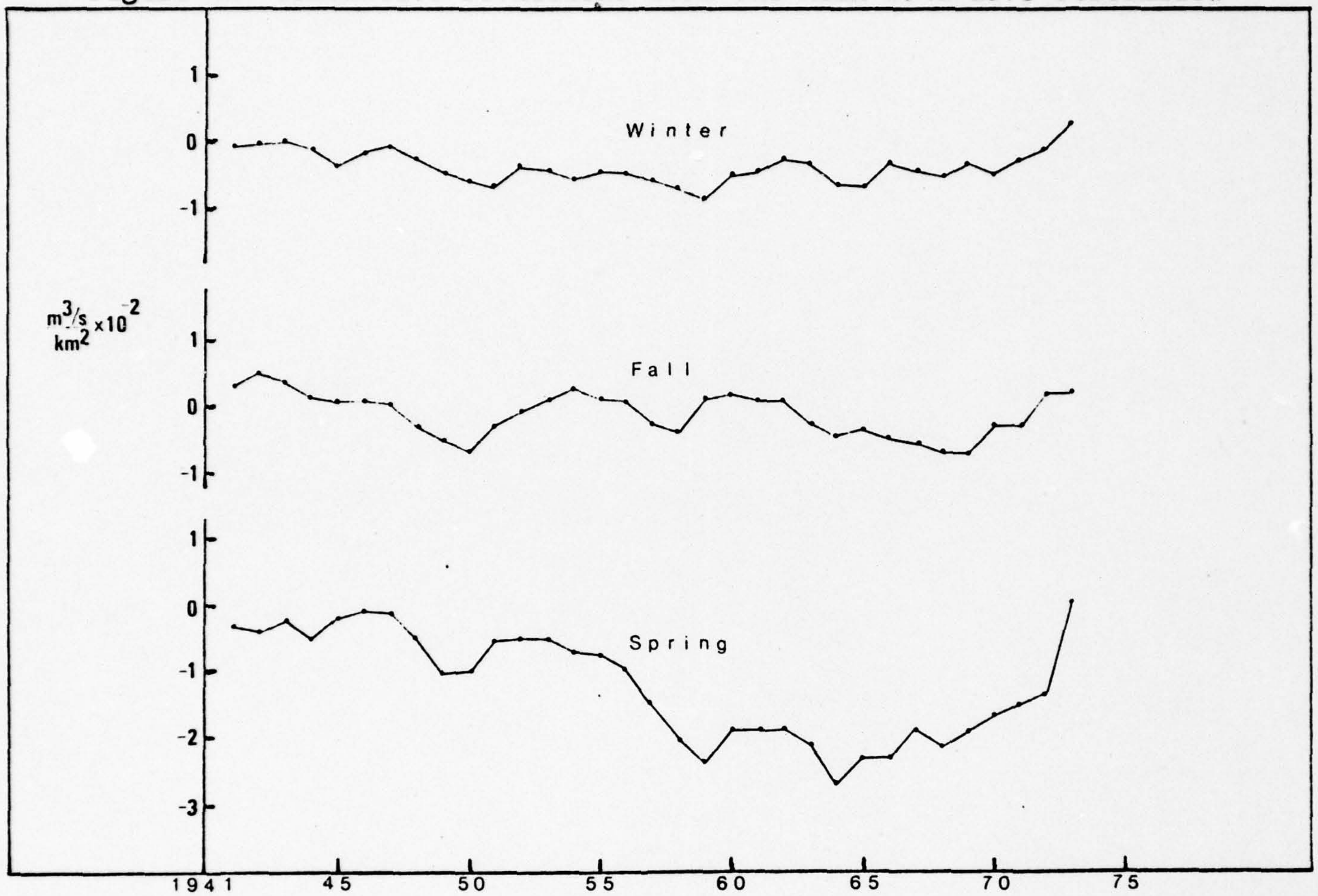
terval is wetter during the time of meridional domination, 1950-1975, when compared to the zonal circulation period, 1925-1949.

Streamflow data, in this case the average monthly discharges from 12 gaging stations upstream of the Columbia Generating Station (Table 2) per unit area, are grouped into the three hydrologic seasons. Graphs of flow versus time (Figure 18A, B, and C), cumulative deviations from the mean (Figure 22), and 5-year and 10-year running means (Figures 20 and 21) are employed in the analysis. Winter flow is sensibly constant throughout the entire period of record, which is unfortunately only 1941-1973 because of the limited gaging station data available. However, both the Fall flows and the Spring flows, especially the latter, exhibit a trend toward increasing flow, particularly since about 1960. Because of river regulation, perhaps most emphasis should be placed on the precipitation data. However, the manner in which the streamflow data are presented is the most accurate reflection of the flow's relationship to precipitation and climate regime which can be used for a river that contains dams and reservoirs. The streamflow data are of significance; their only real shortcoming is the length of their record.

Analysis

On the basis of the precipitation and streamflow data for both of the periods analyzed, 1873-1910 and 1925-1975,

Figure 22: Cumulative Deviations from the Mean 1941-1973 Streamflow



a number of statements can be made: (1) that the change from a zonal to a meridional regime around 1950 is not nearly so well reflected in the data as was the opposite change in regimes which occurred around 1885 (although this development may be influenced by some bias in the study's period of analysis 1873-1910 resulting from the inclusion of the decade 1875-1885, a period of possible exceptional wetness in the Upper Mississippi Valley region (Knox et al., 1975)); (2) that the only season in the later period that depicts both of the characteristics thought to accompany a meridional regime, increased precipitation and persistence of variability, is the Fall, and even then the results are less than conclusive; (3) that persistence of variability carries through both periods in only the Spring season, but there is no evidence that the Spring meridional regime is wetter than the zonal regime in the 1925-1975 period; and (4) that the Winter season is anomalous in both periods, as it exhibits no increased precipitation in the meridional regimes nor any persistent year-to-year variability that can be dissociated from the variability of the zonal regimes.

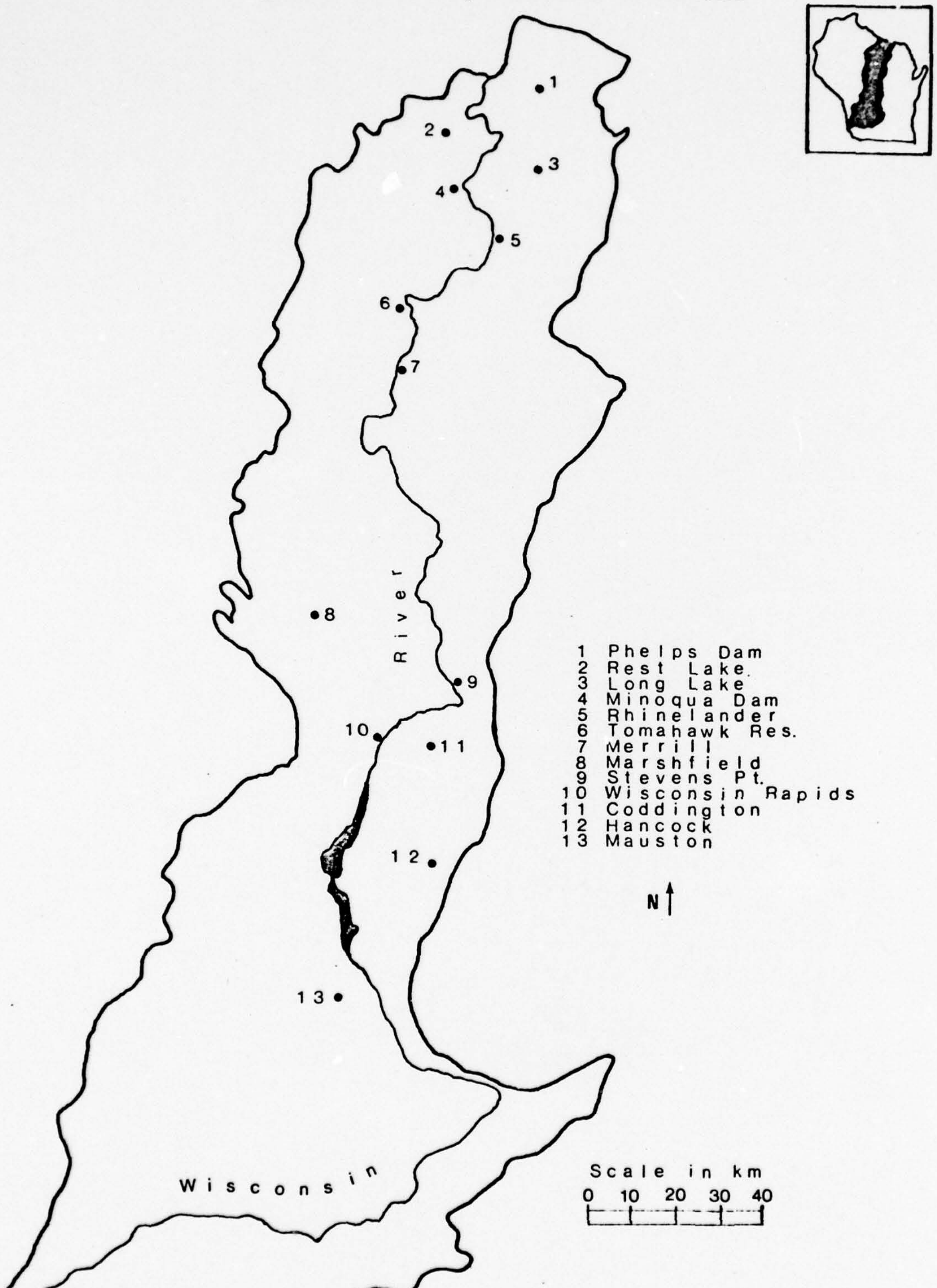
The precipitation and streamflow data for the Upper Wisconsin River Valley do not provide conclusive evidence for a change in climate around 1950. Only the Fall season shows a trend toward above-average precipitation since that time. Persistence of variability does exist in the Fall, but it occurs throughout the entire 1925-1975 period. Only the Spring season has variability that is more persistent in

the meridional regime than in the zonal regime. The Winter season has no characteristics of a meridional regime. Neither greater precipitation values nor persistence of variability exist in the post-1950 Winter data. Any variability that is evident in the Winter occurs during the pre-1950 zonal regime.

It appears that the Fall season is the only time which may have a significant effect on hydrologic data because of the change to a wetter and colder meridional regime. For the study area, the Fall is a season of great significance because the dams and reservoirs have no storage effect on flood flows during that time (Sherrar, 1976a). Since the recent data exhibit a trend toward increased precipitation and higher discharges in the Fall, the analysis includes a detailed examination of the rainfall data for that season. Precipitation data at each weather station (Figure 23) for the months of April through September are analyzed. Before the analysis continues, however, a look at the "normal" precipitation regime for the Spring and Fall seasons is appropriate.

Descriptions of the "normal" precipitation regime of Wisconsin are provided by Trewartha (1961) and Barry and Chorley (1970). Both sources depict the precipitation record as containing a double maximum with precipitation peaks in May-June and August-September. The area of the Upper Mississippi River has a secondary minimum which usually occurs in July-August even though the air is quite warm and

Figure 23: Study Weather Stations



moist. A ridge of high pressure over the Mississippi Valley is apparently responsible for decreased summer thunderstorms and the resultant secondary precipitation minimum. Normally, cyclonic activity increases again in early September as the polar front shifts to the south and clashes with warm, moist mT (maritime Tropical) air from the Gulf of Mexico. Frontal wave activity increases, making the first half of September a rainy period in Wisconsin. After about the 20th of the month, anticyclonic conditions return, bringing warm, dry weather conditions commonly referred to as an Indian summer.

Trewartha (1961) concludes that the summer rainfall in Wisconsin is primarily the result of large-scale synoptic conditions rather than the consequence of random thermal convection. Barry and Chorley (1970) point to the incursion of polar air in early September and the resultant clash with air from the Gulf as the cause of the second precipitation maximum in September, although Trewartha (1961) states that in northern Wisconsin the same maximum occurs in August. The secondary minimum, normally in July or August, corresponds with periods of great anticyclonic activity. The Indian summer in the second half of September is associated with anticyclonic conditions resulting from strong zonal flow.

Bryson and Lahey (1958) hypothesized that the sharp increase in precipitation during April, which culminates in the first precipitation maximum in May-June, is related to

a decline in the zonal index. The precipitation maximum is the result of a change in the wave numbers of the Rossby long wave patterns with an accompanying shift in the positions of low pressure (trough) locations. Simultaneously, an increase in frontal activity with resultant rainfall occurs. They attribute the mid-summer precipitation minimum to the northward movement of the Subtropical High Pressure cells and accompanying prevalence of anticyclones. Increasing meridional flow in early September causes the warm, moist Gulf air to rise over the cold cP (continental Polar) air from Canada. The results are the high precipitation totals which produce the second precipitation maximum in either early September or late August. Increased zonal flow occurs in mid-September. This westerly airflow halts the polar air-Gulf air clashes and produces the warm, dry Indian summer.

Trewartha (1961) based the conclusions of his study on data from two periods of time, 1906-1935 and 1920-1950. Both periods fall within the pre-1950, post-1895 zonal climate regime proposed by Lamb (1966) and Knox and others (1975). Barry and Chorley (1970) do not refer to any specific data base, nor do they cite Trewartha (1961) or Bryson and Lahey (1958) in their bibliography. Bryson and Lahey used data from the years 1899-1944 in their study. These years are also within the period of strong zonal airflow. The descriptions of the "normal" summer and fall precipitation characteristics rely on alternating periods of meridio-

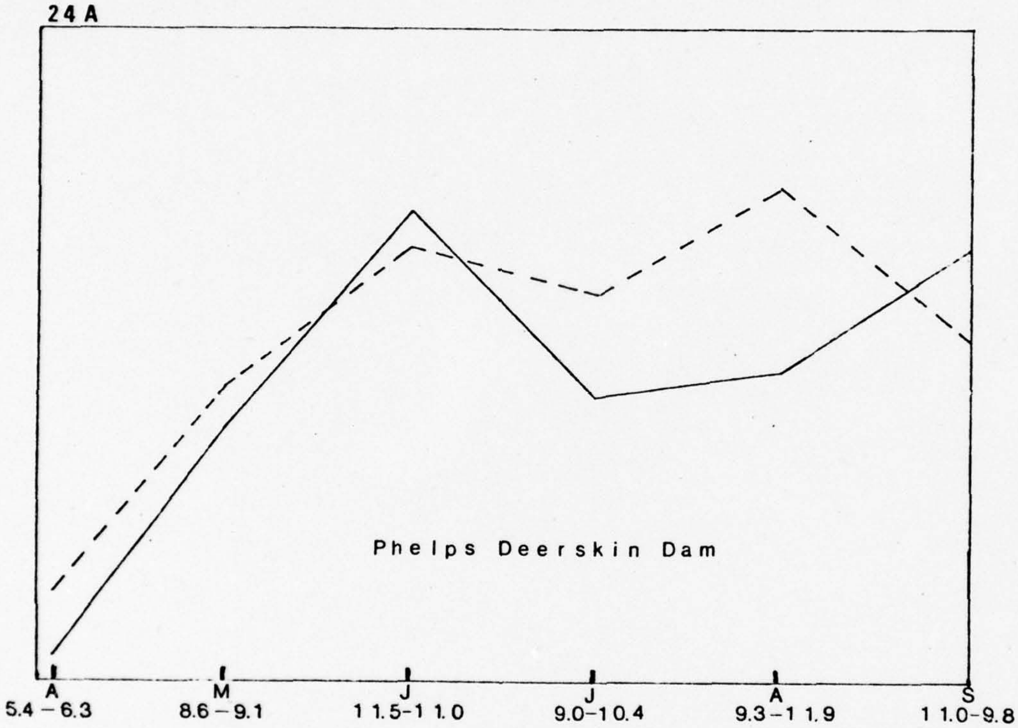
nal and zonal flow to account for the double maximum and secondary minimum precipitation characteristics. When one considers that the data bases used in the studies were all from times of dominant zonal flow (approximately 1885-1949), it is significant to consider how those characteristics could be altered if the data included precipitation values from the 1950-1975 regime of meridional circulation. Since the Fall season exhibits a trend toward increased precipitation and since during the Fall the dams and reservoirs have no storage effect on the flood flow of the Wisconsin River, the analysis examines the precipitation at each weather station in order to see how data from a meridional regime may affect the "normal" precipitation characteristics.

Graphs of the monthly rainfall from each of the 13 weather stations depict how the zonal data from 1925-1949 and the meridional data from 1950-1975 compare (Figures 24A through G). The zonal flow data plot, without exception, in the manner prescribed by Trewartha, that is, with a double maximum and a secondary minimum. All stations have the first peak in June and all but Rest Lake have their second peak in September. All stations have the secondary minimum in either July or August. Thus, the precipitation data match the "normal" precipitation characteristics described above at all stations during the period of zonal airflow.

However, the data for the 1950-1975 period of meridional flow possess quite different characteristics. The most obvious change in characteristics is probably the marked re-

Figures 24A through 24G: Precipitation at each Weather Station

24 A



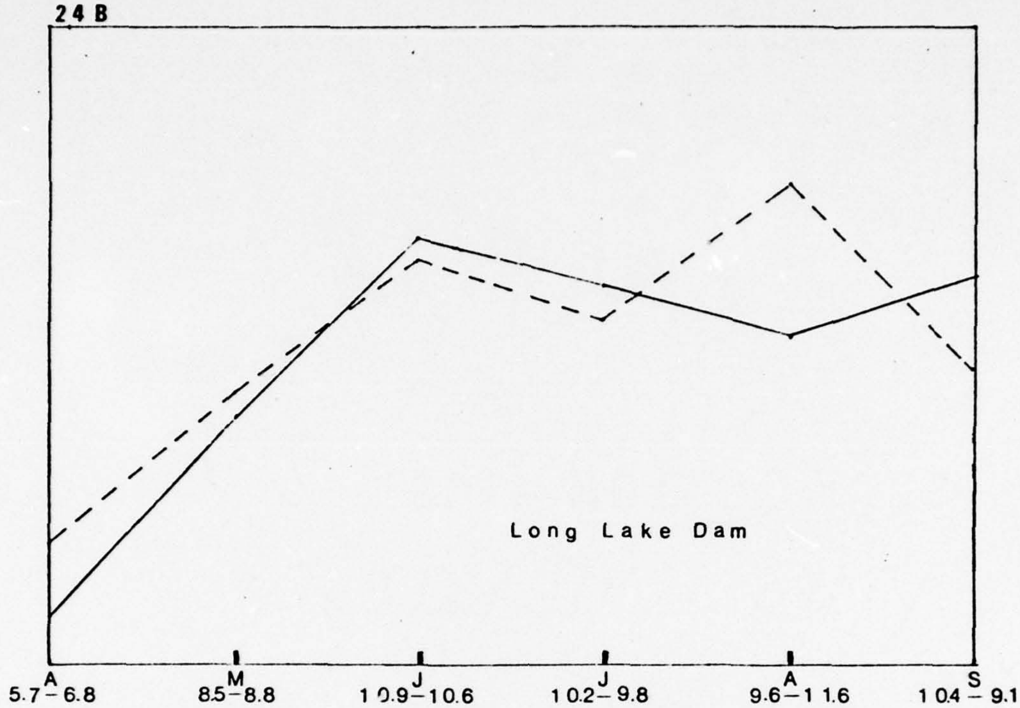
Legend for Figures 24A-G

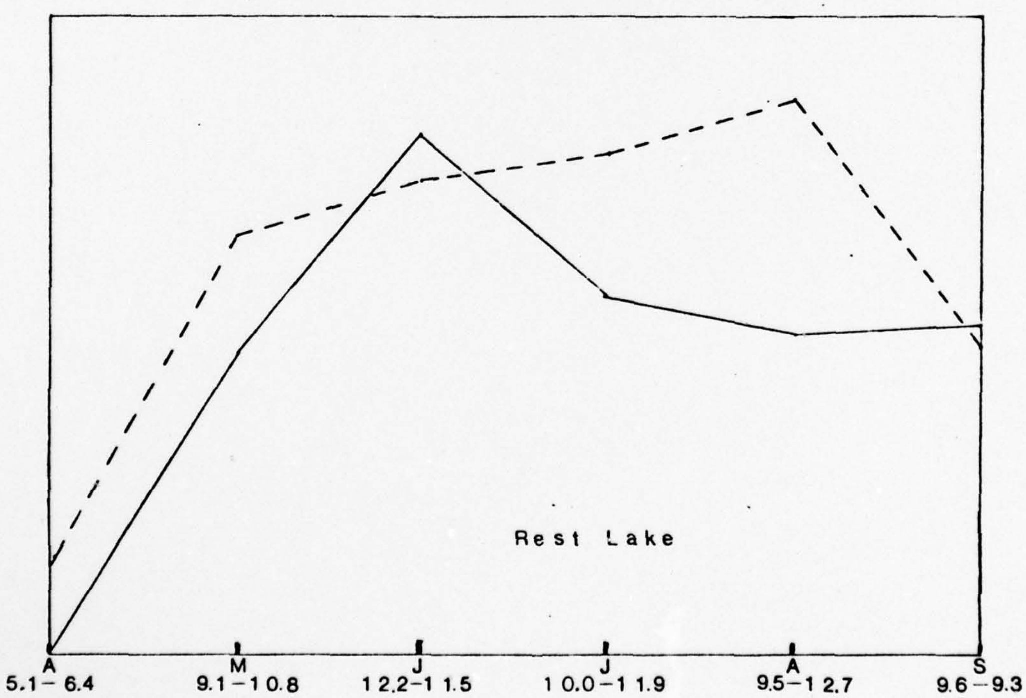
—— 1925-1949
- - - 1950-1975

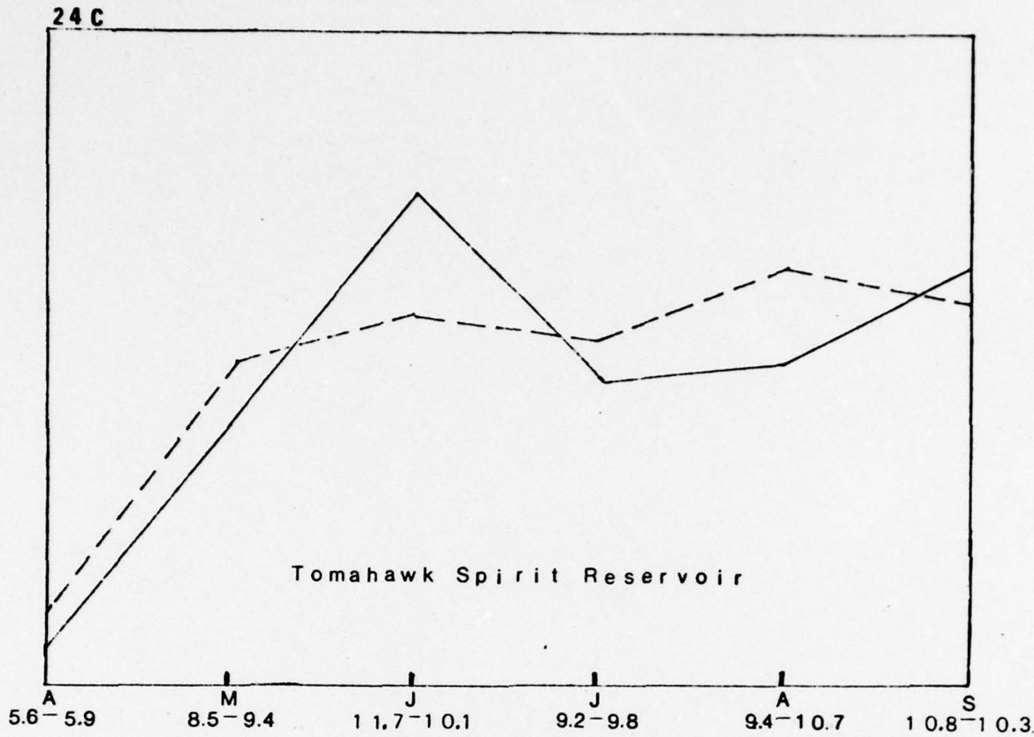
A 5.4–6.3 is April Rain
5.4cm for 1925-49
6.3cm for 1950-75

M 8.6–9.1 is May Rain

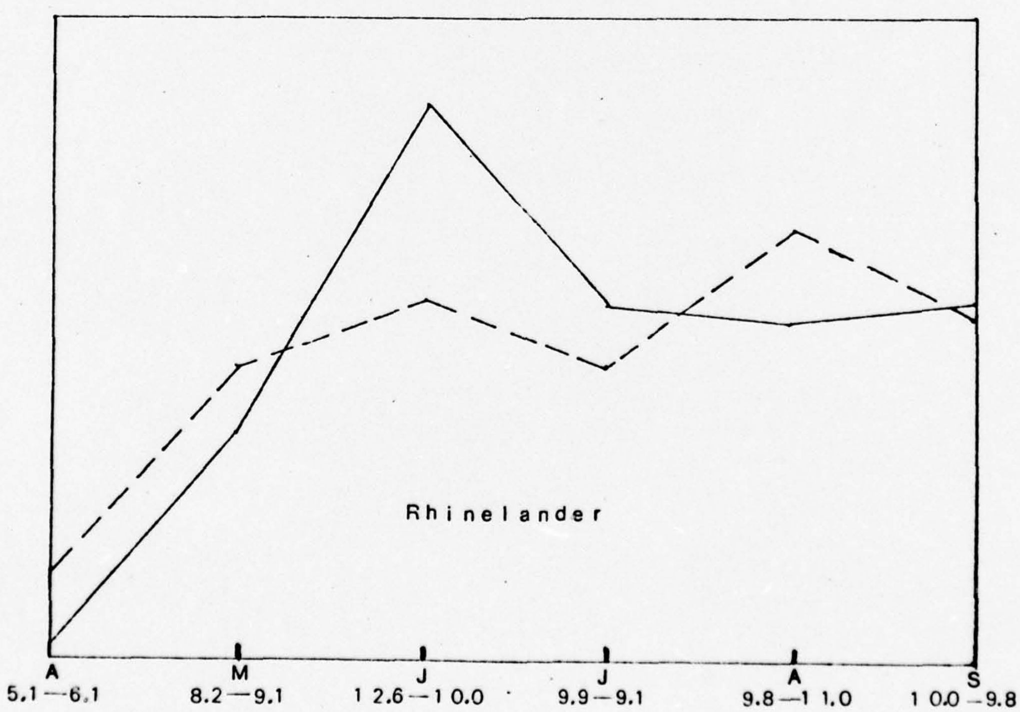
etc.


24 B
Long Lake Dam
A
M
J
J
A
S
5.7–6.8
8.5–8.8
10.9–10.6
10.2–9.8
9.6–11.6
10.4–9.1

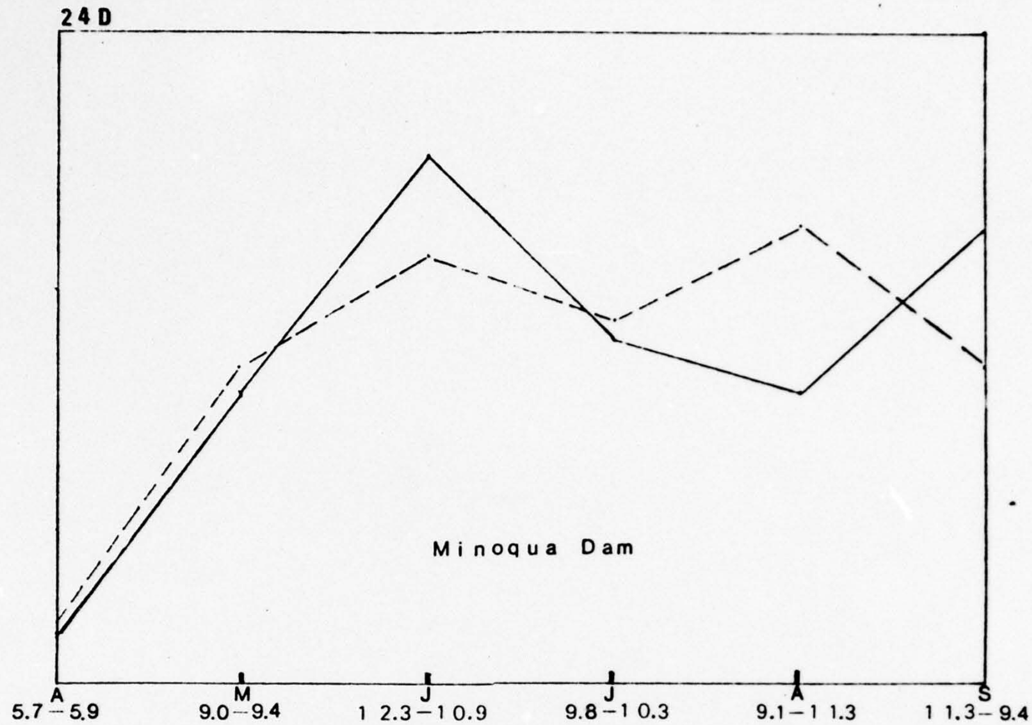

Rest Lake
A
M
J
J
A
S
5.1–6.4
9.1–10.8
12.2–11.5
10.0–11.9
9.5–12.7
9.6–9.3

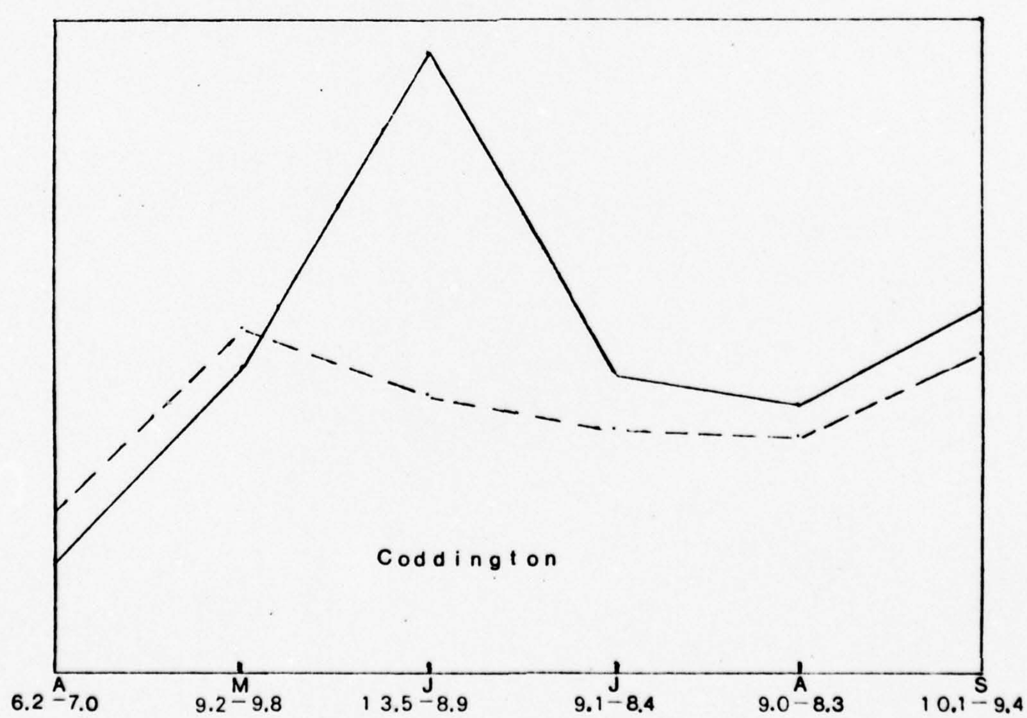


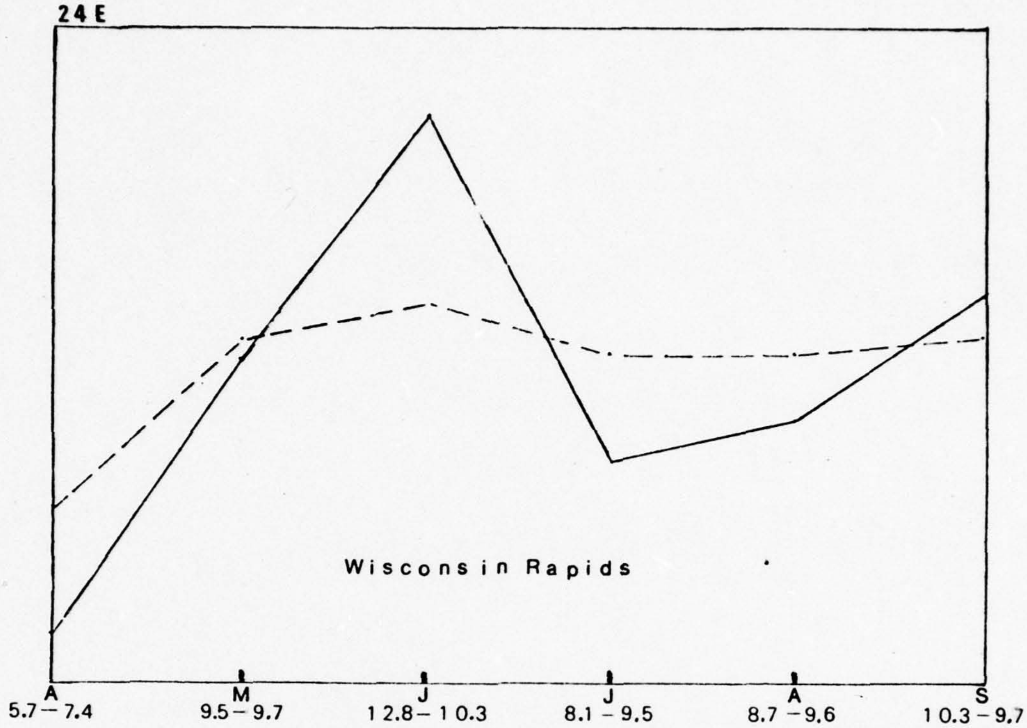
24 C
Tomahawk Spirit Reservoir
A
5.6 — 5.9
M
8.5 — 9.4
J
1 1.7 — 1 0.1
J
9.2 — 9.8
A
9.4 — 1 0.7
S
1 0.8 — 1 0.3



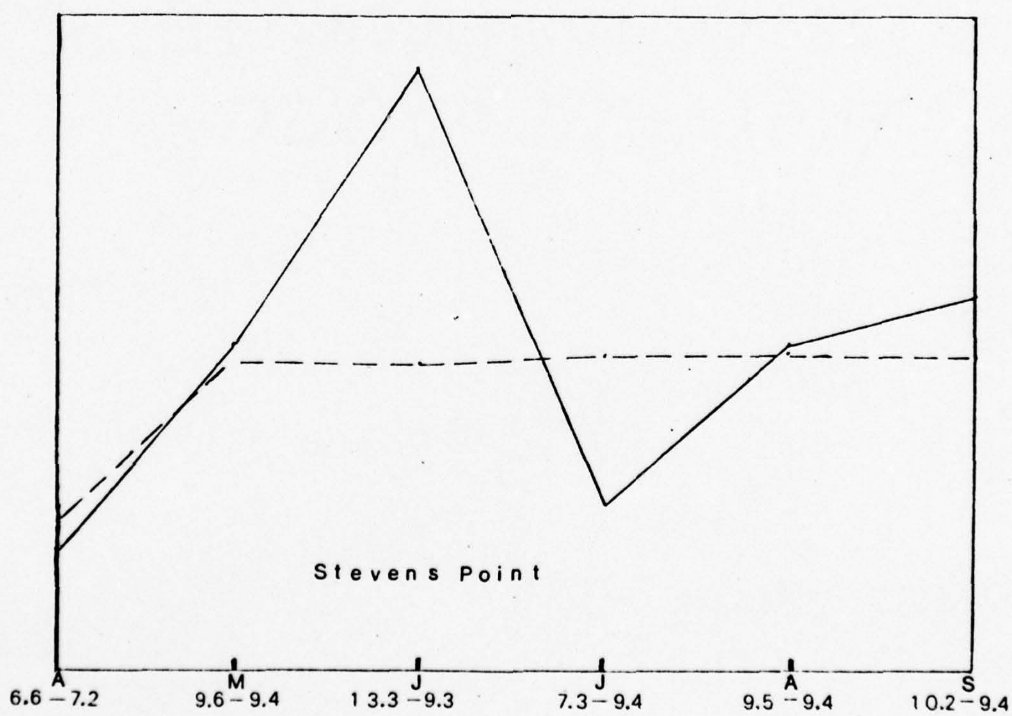
Rhinelander
A
5.1 — 6.1
M
8.2 — 9.1
J
1 2.6 — 1 0.0
J
9.9 — 9.1
A
9.8 — 1 1.0
S
1 0.0 — 9.8


24D
Minoqua Dam
A
M
J
J
A
S
5.7 – 5.9
9.0 – 9.4
12.3 – 10.9
9.8 – 10.3
9.1 – 11.3
11.3 – 9.4


Coddington
A
M
J
J
A
S
6.2 – 7.0
9.2 – 9.8
13.5 – 8.9
9.1 – 8.4
9.0 – 8.3
10.1 – 9.4

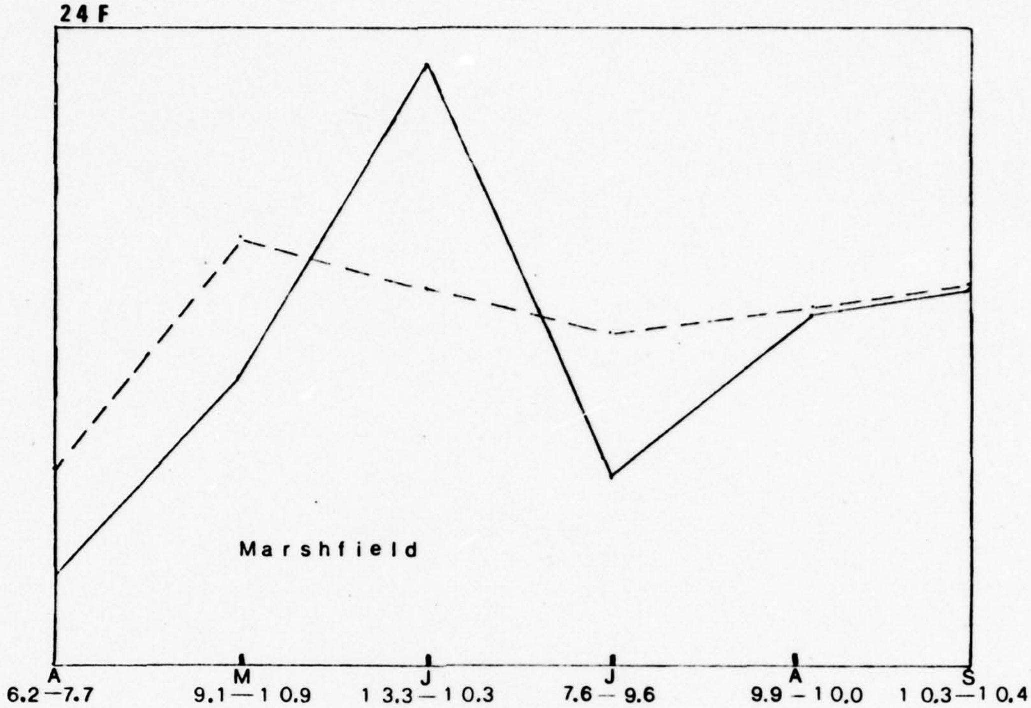


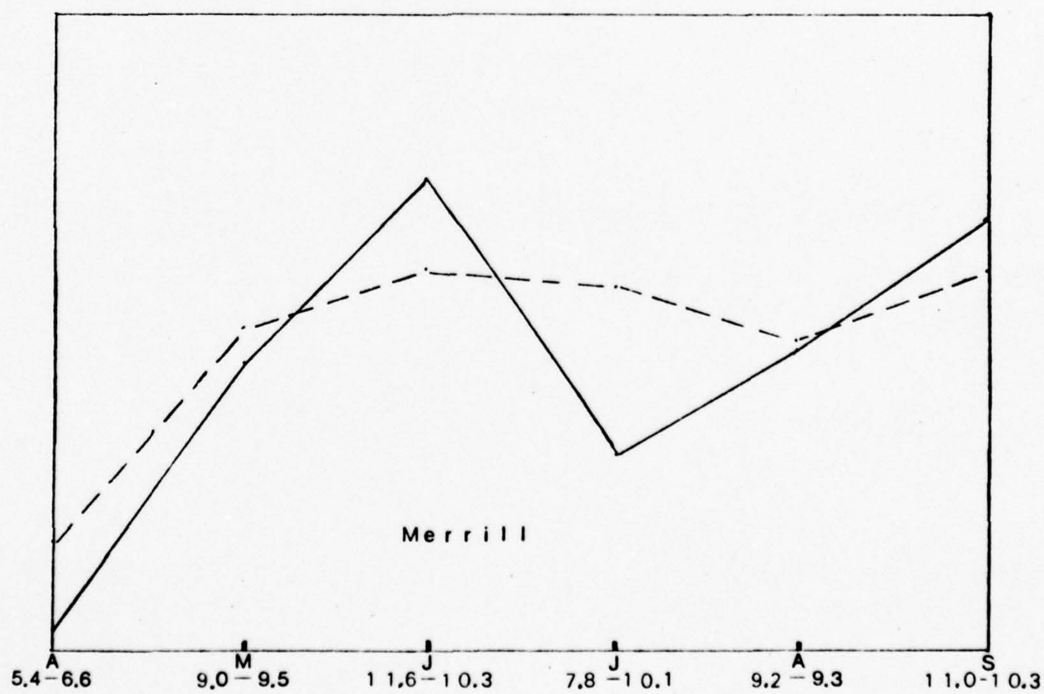
24 E
Wiscons in Rapids
A
5.7 — 7.4
M
9.5 — 9.7
J
12.8 — 10.3
J
8.1 — 9.5
A
8.7 — 9.6
S
10.3 — 9.7



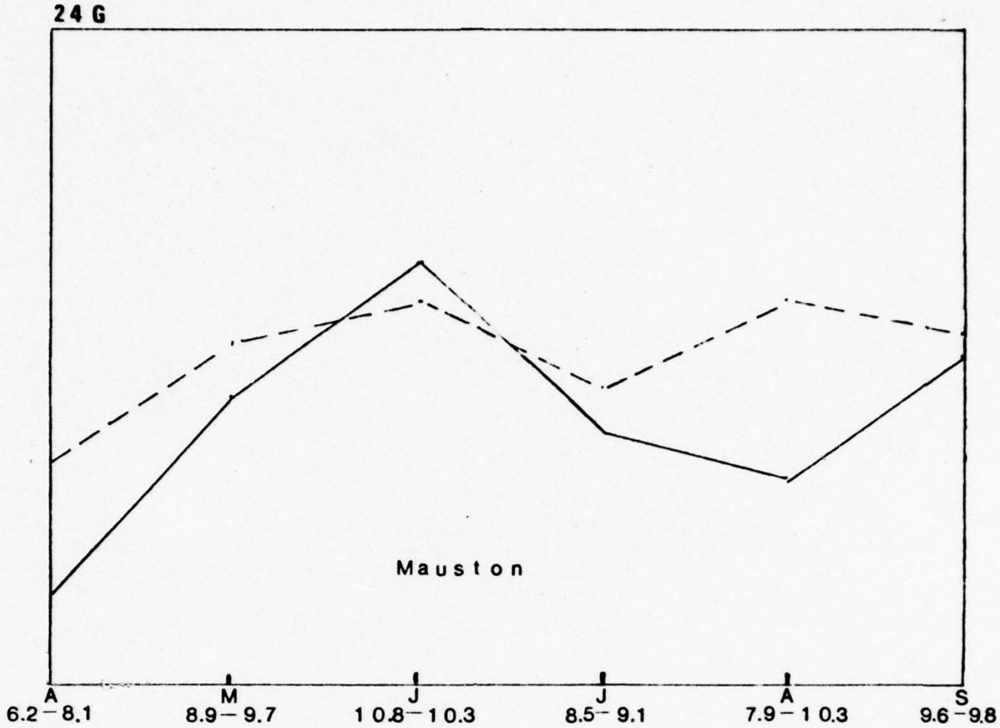
Stevens Point
A
6.6 — 7.2
M
9.6 — 9.4
J
13.3 — 9.3
J
7.3 — 9.4
A
9.5 — 9.4
S
10.2 — 9.4

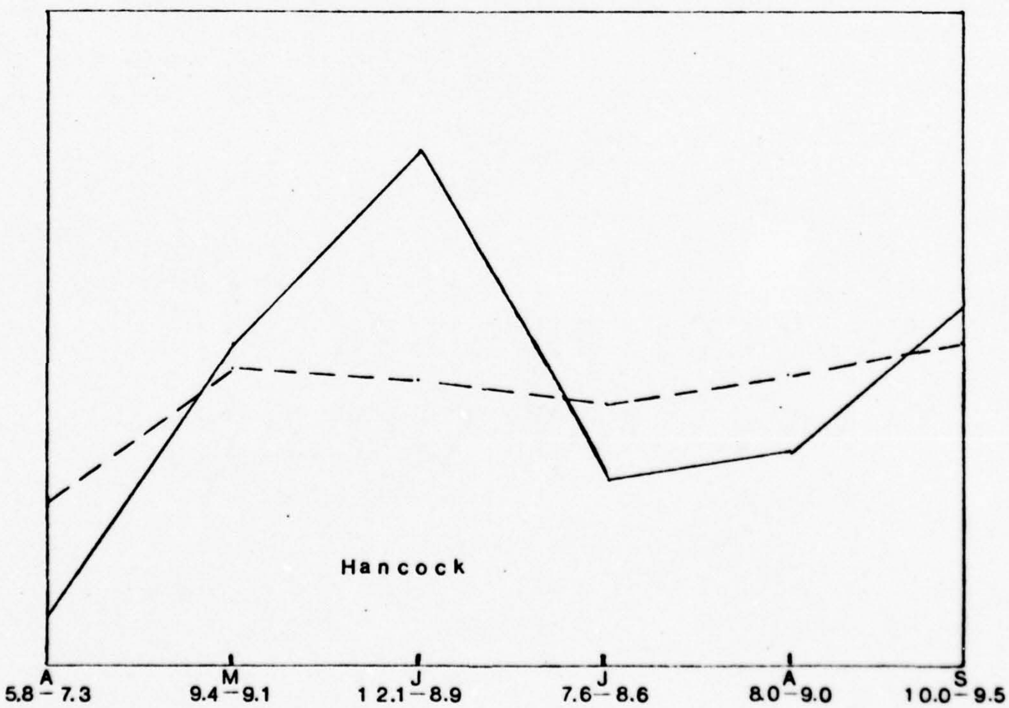
24 F


Marshfield
A
6.2 — 7.7
M
9.1 — 1 0.9
J
1 3.3 — 1 0.3
J
7.6 — 9.6
A
9.9 — 1 0.0
S
1 0.3 — 1 0.4


Merrill
A
5.4 — 6.6
M
9.0 — 9.5
J
1 1.6 — 1 0.3
J
7.8 — 1 0.1
A
9.2 — 9.3
S
1 1.0 — 1 0.3

24 G


Mauston
A
M
J
J
A
S
6.2 — 8.1
8.9 — 9.7
10.8 — 10.3
8.5 — 9.1
7.9 — 10.3
9.6 — 9.8


Hancock
A
M
J
J
A
S
5.8 — 7.3
9.4 — 9.1
12.1 — 8.9
7.6 — 8.6
8.0 — 9.0
10.0 — 9.5

duction in the magnitude of the June peak, and, in some cases, the elimination of that peak. Another significant change is the shift of the second precipitation maximum from September to August at many stations. The initial peak has also shifted from June to May at some of the stations. Without exception, the month of April is wetter during the 1950-1975 period. A further change is the increased precipitation during either July or August or both at all of the stations except Coddington. Finally, precipitation totals decreased in September at all but two of the stations.

From the graphs of the monthly precipitation at each station, it is quite apparent that the precipitation characteristics no longer resemble those previously considered to be "normal". This analysis of monthly rainfall demonstrates that, indeed, the climate in the study area has changed since 1950. A trend toward increased precipitation has been shown to exist in the Fall hydrologic season. Monthly data at each station depict that the timing and amount of precipitation during the months of April through September have changed markedly. The characteristics of the meridional climate of the post-1950 period are not strikingly similar to those of the pre-1885 meridional regime (again, this fact may result partly from the possibility of extreme wetness during the 1875-1885 period), but no matter, the analysis has demonstrated without qualification that the characteristics of the Fall and most of the Spring hydrologic seasons during the years 1950-1975 reflect a different climate

regime from the characteristics of those years dominated by strong zonal airflow.

CHAPTER VII

THE REAPPRAISAL

The change in climate since 1950 for the Upper Wisconsin River Valley is best manifested in the altered timing of "normal" rainfall during the months of April through September. The Fall hydrologic season has recorded higher precipitation averages since that time, even though some months in that season have not. Some months during the Spring hydrologic season also have had greater precipitation averages since 1950. An evaluation of the impact of the demonstrated change in climate on the study problems is appropriate.

In light of the change in "normal" precipitation characteristics, the discharge values obtained from the USGS and the Corps of Engineers may not be representative. The intent of this chapter is to develop streamflow data for the existing climatic regime. Unfortunately, no simple procedure for the proposed task exists. The rainfall data, monthly and seasonal, do not provide a means of predicting discharge. Normally, storm rainfalls of short duration (hours) or steady rainfalls of long duration (days) are employed to generate peak streamflow values. An indirect approach to the problem of discharge formulation involves a comparison of magnitudes and frequencies for two time periods. A correction factor can be developed to account for any difference between the two distributions. With the data

available for this research, only the indirect approach is feasible.

The data for the analysis are the maximum gage heights (stages) of the Wisconsin River at the Portage canal. There, the US Weather Bureau maintains a crest gage which has a period of record compatible with that of the precipitation data used in Chapter VI. Monthly stages for the 1924-1975 period were examined in order to produce an annual flood series. The period was divided in half, with a zonal interval 1924-1949 and a meridional interval 1950-1975. Each interval was treated as a separate population with its own distribution of flood frequencies. The formula used for the recurrence interval was r.i. = N + 1/M. Results were plotted on Gumbel probability paper.

Three flood frequency determinations were made both for the zonal and for the meridional intervals: one for the Snowmelt period (December through April), one for the Rainfall period (May through November), and one for the entire year. The Snowmelt curves (Figure 25) show larger floods for most recurrence intervals since 1950. Not much weight can be placed on these results, however. River regulation and ice jams affect the Snowmelt frequency distributions. Ice can cause backwater, which produces misleading stages at the crest gage (Dalrymple, 1960). Reservoir storage is a factor in the springtime, as the reservoirs are carefully monitored to control snowmelt runoff (Sherrar, 1976b). The yearly flood frequency curves are equally suspect, since they in-

clude the Snowmelt data.

The flood frequency determination for the Rainfall interval is not affected by either of the aforementioned problems; therefore, it should provide a reasonable reflection of the climate during 1924-1975. With the *a priori* knowledge gained from the climate change analysis, one would expect the flood frequency distributions for the zonal and meridional periods to differ from one another. A graphical comparison of the two distributions (Figure 25) shows virtually no difference between the two curves. To check the situation further, all events with stages greater than flood stage (5.2 m) for the interval 1909-1923 were incorporated into the zonal regime data by a method that considers historical floods (Benson, 1962). No data are available for 1900-1908. Data from the years before 1900 are not valid in this analysis, because the Portage levees in their present form did not exist until 1900 (EIS, 1974). Again, a graphical comparison between the zonal and meridional distributions shows virtually no difference (Figure 26).

The Portage stage data indicate that the meridional regime has had no noticeable effect on the flow of the Wisconsin River in the study area. Two possibilities exist: either the new climate has had no effect, or it has had an effect which cannot be determined with the method and data used. In either case, representative discharges for the post-1950 climatic regime, that differ quantitatively from those of the pre-1950 regime, cannot be determined in the course of the

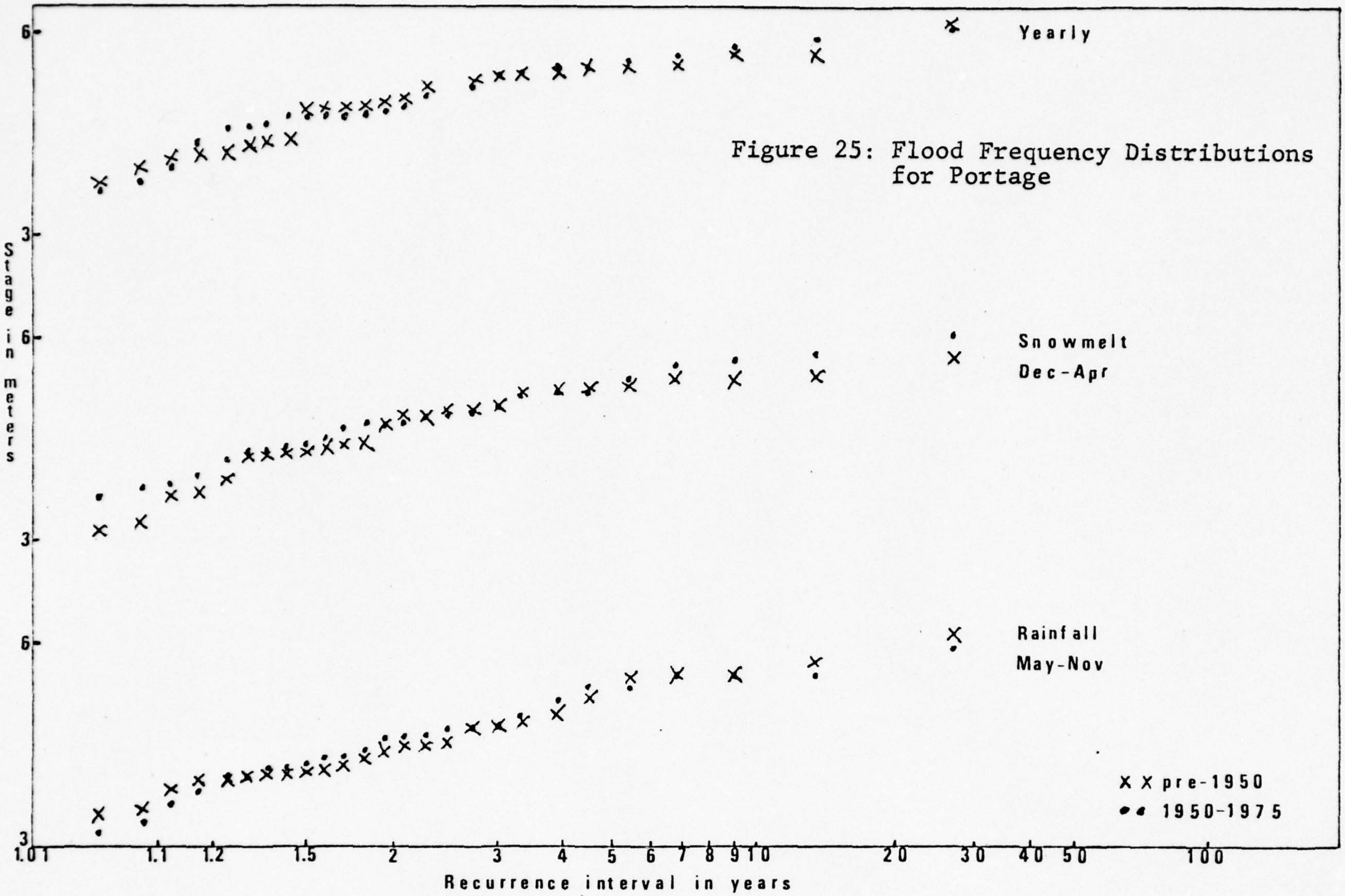


Figure 25: Flood Frequency Distributions for Portage

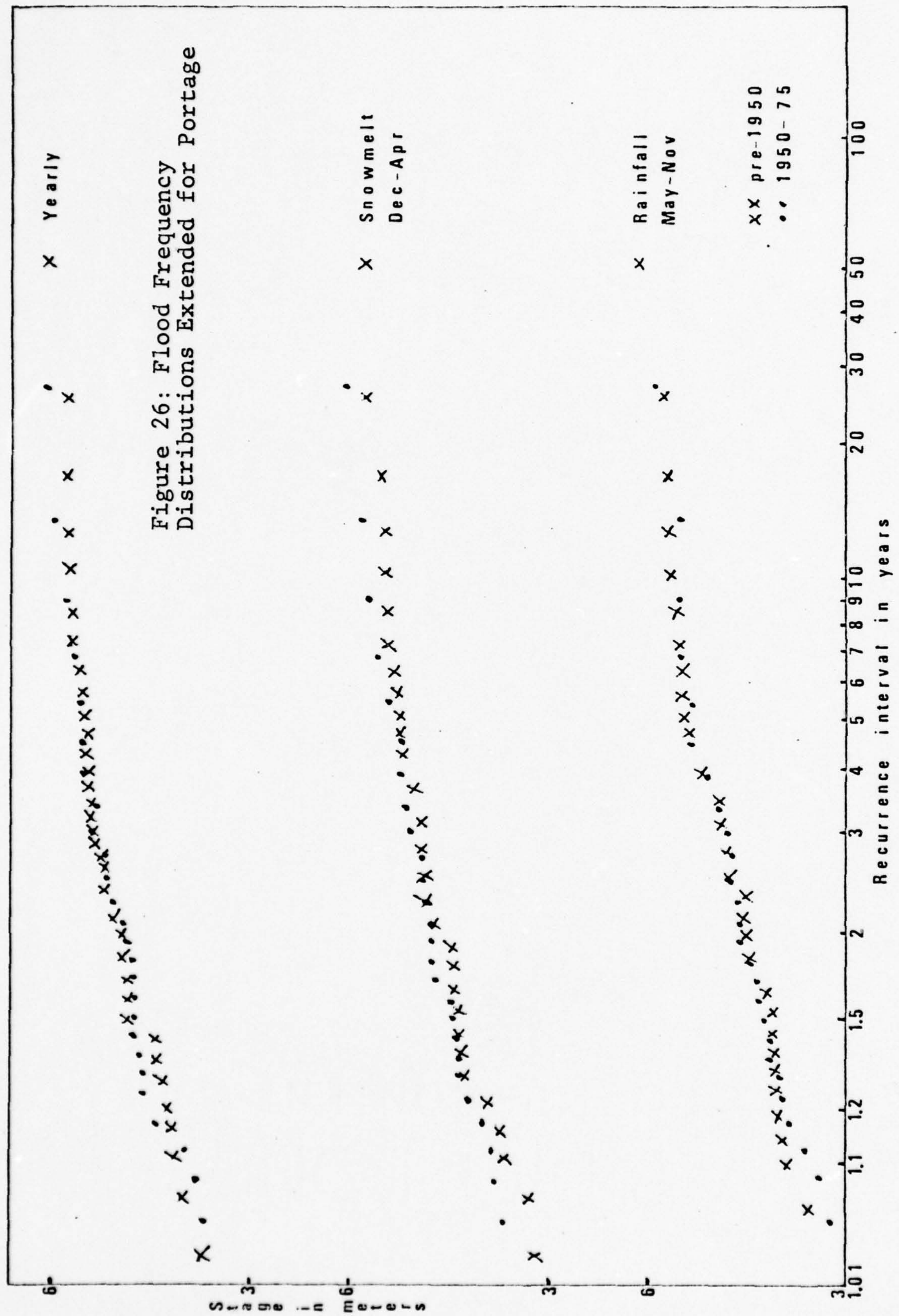


Figure 26: Flood Frequency Distributions Extended for Portage

present research. This is unfortunate, because the graphs of the monthly precipitation at each weather station (Figures 24A-G) indicate antecedent conditions for the meridional regime that are markedly different from those of the zonal regime. For geomorphic problems, such as scour, antecedent conditions are primary considerations. Because of the failure of the quantitative effort at discharge prediction, only subjective thoughts as to the effects of the climate change can be presented.

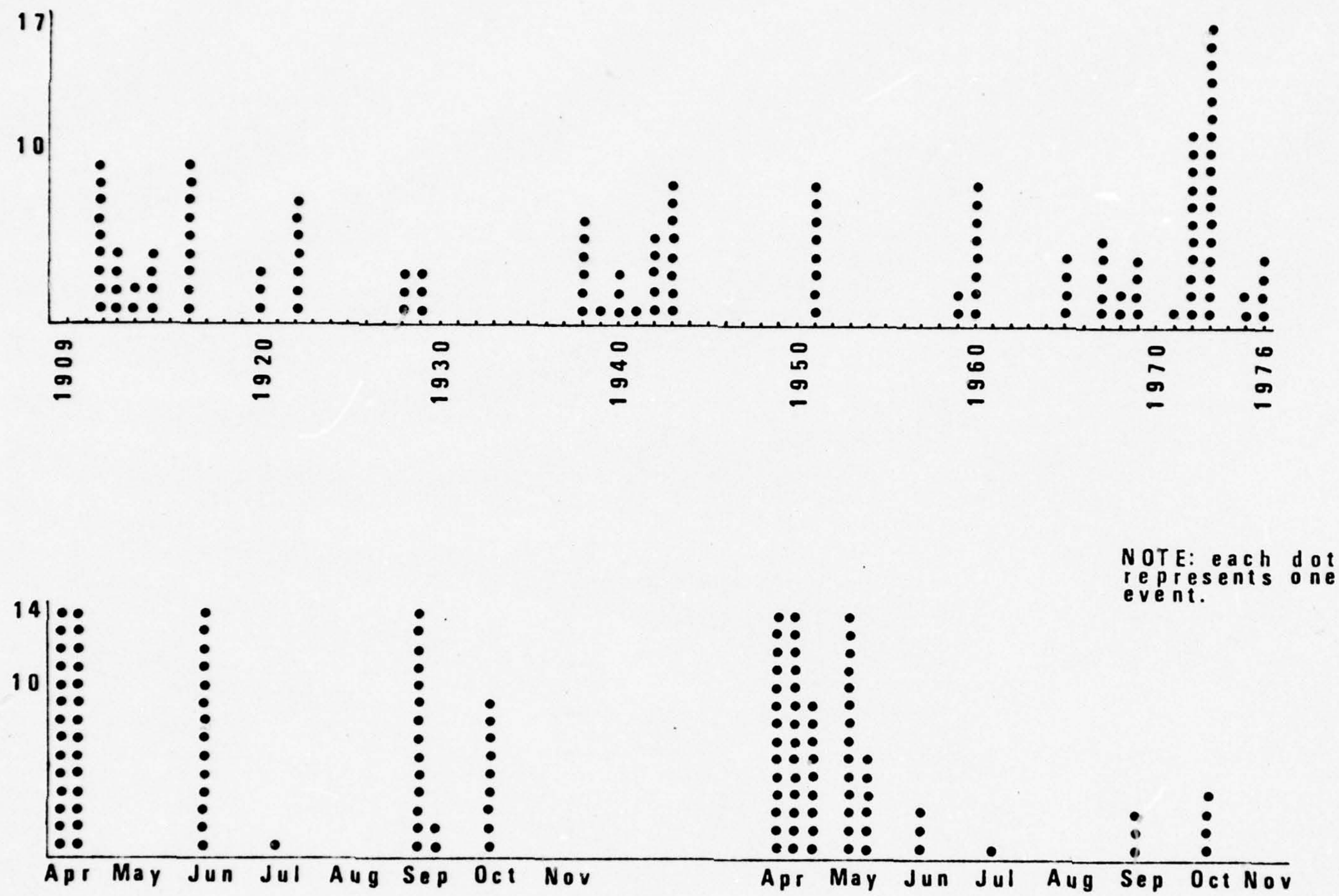
Some of the changes in precipitation characteristics since 1950 are applicable to all stations: Junes and Septembers are drier than before, while Aprils are wetter at all but two stations. In the northern portion of the Upper Wisconsin Valley, Augusts are wetter at all stations (Figure 23, stations 1-6) and Julys are wetter at three stations, drier at two, and unchanged at one. The situation in the southern portion (Figure 23, stations 7-13) differs somewhat, as Augusts are wetter at only three stations, but Julys are wetter at all but one. Precipitation averages during May have remained constant throughout the entire 1925-1975 period at all stations.

Changes in the timing of "normal" rainfall should have had effects on many geomorphic processes in the study area. The indicated changes could have affected thresholds of stability, and thus have had a major impact on the results of any analysis of the possibility of scour. Soil moisture conditions could have been so altered that discharges that were

once geomorphically ineffective would now have the ability to do much geomorphic work. The changed precipitation regime, with its different antecedent conditions, might cause more frequent high-magnitude floods during the Rainfall interval than the present flood frequency determinations would predict. A comparison between the zonal and meridional periods of the number of days when the Wisconsin River was above flood stage (flood-days) at Portage is worthy of consideration in this regard.

An examination of the number of flood-days, obtained from the US Weather Bureau's Daily River Stages, provides inconclusive results. For the zonal interval 1909-1949, there were 40 flood-days, exceeding by 9 the 31 flood-days of the 1950-1976 meridional period. Because the length of record for the two periods differs, it may not be apparent that, on the average, most flood-days per Rainfall interval have occurred during the meridional climate regime. However, the difference in the averages between the two periods is small--1.15 flood-days per Rainfall interval in the meridional regime compared to 0.98 flood-days per Rainfall interval in the zonal regime. An analysis of the temporal distribution of flood-days is of greater value (Figure 27). A readily apparent observation is the striking increase in flood-days during May, from none in the zonal period to 20 in the meridional interval. On the other hand, the number of flood-days in June, September, and October decreased in the meridional period. Importantly, the changes in the timing of flood-

Figure 27: Temporal Distribution of Flood Days at Portage
(for months of April through November)



days at Portage corresponds quite well with the various changes in the timing of precipitation maxima and minima in the Upper Wisconsin River Valley (See Figures 24A-G and 27). It is surprising to note the absence of any flood-days in August, especially considering the precipitation increases throughout the Wisconsin River drainage basin above Portage during that month.

If the April flood-days could be included in the analysis, the difference in the number of flood-days between the two climatic regimes would be noteworthy. In fact, there would be an average of 2.51 flood-days per Rainfall interval in the meridional regime and only 1.65 events per Rainfall interval in the zonal period. However, April is a month which may have floods resulting from either snowmelt runoff, excess rainfall, or a combination of the two preceding causes. Because of the uncertainty about the origin of the April flood stages, the data from that month cannot be included in the analysis.

The small difference in the number of floods per Rainfall interval between the two time periods provides no support for the hypothesized changes in hydrologic response expected with a shift to a meridional climate regime. The changes in the temporal distribution of flood-days may provide such support. It appears, in the Upper Wisconsin River Valley at least, that the climatic change of 1950 is manifested not only in the changed timing of "normal" rainfall, but also in the altered timing of flood-days. Such a devel-

opment emphasizes the necessary consideration of antecedent conditions in the study of geomorphic processes.

The analysis in Chapter IV of the scour potential demonstrated that a possibility exists for the occurrence of scour during the 100-year flood. The discharge value of 2690.4 m^3/s used for the 100-year flood may be too small. The Corps of Engineers had recognized a value of 2973.6 m^3/s before agreement with the USGS on the smaller value (EIS, 1974). A discharge, not much larger than the one used in the present study for the 100-year flood, could produce the threshold velocity necessary to scour the sandy, unvegetated areas of the floodplain and west dike. Computer runs for two large, hypothetical discharges provide some idea of extreme velocity-discharge relationships at cross-section 8. Velocities of 48.8 cm/s and 54.9 cm/s resulted from discharge values of 4493.0 m^3/s and 5380.8 m^3/s respectively. Somewhere between the lowest of these discharge values and the value of the 100-year flood used in the present research lies that discharge which produces just the velocity required to initiate particle motion in the study area. However, at this point everything is conjecture. A rigorous analysis of existing data leads to no conclusive evidence for the occurrence of scour or excessive backwater, even when the climate change since 1950 is taken into account.

CHAPTER VIII

CONCLUSIONS

Scour along the west dike and on the floodplain surface near cross-section 8 may occur during the 100-year flood. There appears to be no possibility of scour during the 2-year and 10-year events. The backwater effect, as a result of the encroachment of the Columbia power plant, does not exceed the limits established by the DNR floodplain zoning ordinance. The greatest increase in water surface elevation is 6.4 cm. This value occurs at a cross-section below the city of Portage, as the backwater effect diminishes upstream from the encroachment. The backwater effect has no significant impact on the normal stage-discharge relationships at Portage or on the Wisconsin River-Fox River drainage situation during flood flows.

Bogardi (1968) recognizes four possible mechanisms for the failure of a dike: wave action, seepage, saturation, and scour. All four apply to the study site. Waves lap the dike on windy days. Water seeps from the cooling lake through the dike. Floods on the Wisconsin River are of long duration (days). However, the present research examines only the last mechanism--scour from the effect of water flowing against the dike and on the floodplain surfaces. The analysis of scour potential employs the assumption that the floodplain and west dike are unvegetated. In reality, they are vegetated. New methods to determine accurate

roughness coefficients for vegetated channels are being investigated by Shen (1973). The results of his work may permit the elimination of assumptions, such as the one aforementioned, and permit researchers to investigate the possibility of scour with the vegetation taken into account.

A possibility of vegetational change exists in the sedge meadow, because of thermal and other effects resulting from the power plant (Willard, 1977). The occurrence of such change could affect the flow hydraulics of floodwaters near cross-section 8. Floating mats of peat during high flows, a troublesome possibility, could also affect expected velocity distributions in the study area. Erosion, as a result of overland flow, is possible on the west dike. The dike soils have high erodibility indices (Wischmeier, 1973), but the present study does not consider the effects of overland flow. Future research is needed to monitor each of the aforementioned possibilities.

The backwater question is relatively straightforward. An area of confusion is the definition of double encroachment. Double encroachment requires that the amount of conveyance lost because of the encroachment be subtracted from the total amount of water conveyed on the floodplain opposite the encroachment. In other words, the effect of one floodplain project is determined by calculating the effect of a similar project on the opposite side of the river. The combined effect must be considered (Schmied, 1973). Previous studies (EIS, 1974) considered double encroachment

along the entire reach of the study area, from the power plant to the city of Portage. The present study considers only the area directly across from the power plant. The interpretation of the backwater question presented herein follows the intent of the law.

The analysis of climate change produces interesting results, but the results do not lend themselves to easy interpretation. The post-1950 meridional regime is not as dramatic in character as the pre-1885 regime. Only the Fall hydrologic season exhibits a trend toward increased precipitation since 1950. The characteristic of high year-to-year variability is difficult to dissociate from the pre-1950 data in all three hydrologic seasons. Changes in the timing of "normal" precipitation during the months of April through September are amply demonstrated. The different antecedent conditions should affect the stream discharge during those months. Whether the change in antecedent conditions is sufficient to cause a biogeomorphic response (Knox, 1972), even on the smallest scale, is questionable. Over an extended period of time, changes in antecedent conditions are probably more likely to have a geomorphic effect in arid areas as opposed to humid areas, such as the Upper Wisconsin River Valley. Even so, such changes should affect geomorphic thresholds in the study area and, in turn, the complex responses of geomorphic systems (Schumm, 1973). Further research is required to determine the extent of such developments.

The present study is an attempt to determine the ability of a stream during flood flow to do geomorphic work. The study develops a method, albeit in need of refinement, of the type called for by Dury (1973). The method permits evaluation of the potential of a stream to scour its floodplain and floodplain structures during floods of various magnitudes and frequencies. Such a method should be useful in fluvial geomorphology, let alone in a school of neocatastrophism. The analysis of climatic data should provide a basis for further research into the effects of climate change in the Upper Wisconsin River Valley. Most of the goals of this thesis were not attained without qualification, which further demonstrates the complexities involved in the treatment of geomorphic processes. Hopefully, future developments in geomorphology will allow similar studies to achieve their ends without qualification.

APPENDIX 1

Particle Size Analysis (Sieving)

Sample Number	Total Weight	On 8 mm Sieve	On 5.66 mm Sieve	On 4 mm Sieve	On 2.83 mm Sieve	On 2 mm Sieve	On 1 mm Sieve	On 500 μ Sieve	In Pan
1	521.0	100.0	25.5	13.7	11.2	11.3	19.8	41.7	297.8
2	352.7	3.8	0.1	0.6	1.0	1.2	4.3	22.1	319.6
3	577.6	0	143.1	1.7	2.6	1.4	5.5	24.0	401.5
4	398.6	1.2	3	1.7	2.4	2	6.1	24.2	358.0
5	382.7	0	3	1.3	2.5	2.1	7.2	50.0	316.6
6	625.7	11.8	8.8	9.1	11.4	8.9	12.0	54.2	509.5
7	637.6	1.3	1.4	0.7	3.6	4.5	13.4	35.5	577.2
8	398.2	4.4	1.0	3.2	2.2	3.8	8.5	24.7	350.4
9	435.0	5.4	1.9	1.2	0.8	2.5	11.3	32.2	379.7
10	443.4	10.0	1.8	2.5	1.7	2.0	7.5	42.7	375.2
11	529.8	57.3	7.8	4.1	6.2	3.7	7.1	22.9	420.7
12	467.4	2.5	4.7	1.5	3.1	4.2	14.1	24.7	412.6
13	464.6	74.7	6.6	7.8	6.3	6.4	16.9	31.2	314.7
14	405.5	27.7	7.1	8.2	7.0	8.3	18.8	57.2	271.2
15	449.5	10.9	4.1	3.3	2.5	3.3	7.5	44.7	373.2
16	425.3	86.0	11.4	7.7	7.9	7.5	10.9	0.7	293.2
17	437.9	63.0	15.4	8.3	8.6	0.9	12.0	35.5	294.2
18	393.0	0	0.8	1.0	0.8	1.2	0	23.3	365.9
19	360.4	9.3	1.0	3.0	2.0	2.1	5.5	30.4	307.1
20	463.5	0	0	0.8	1.1	1.3	4.2	31.7	424.4
21	365.9	25.0	1.4	3.9	3.4	1.9	7.2	35.6	287.5
22	462.0	130.9	8.6	7.1	6.6	5.9	9.9	21.4	271.6
23	313.1	8.2	1.1	0	1.9	1.0	5.3	24.5	271.1
24	364.0	0	0	0.9	0.4	0.3	3.7	21.5	337.2
25	276.9	0	0.9	0.9	0.6	0.3	2.4	17.1	254.7
26	314.0	151.3	25.2	19.1	12.4	9.8	14.2	15.0	67.0
27	278.2	1.4	0	0	0.6	1.1	14.3	29.8	231.0
28	268.0	0	0	0.7	0.4	0.2	1.3	11.5	253.9
29	275.6	0	0	0.6	0.2	0.2	1.6	14.7	258.3
30	309.2	0	1.0	0.5	0.7	0.3	2.0	28.4	276.3
A	693.8	5.7	5.9	2.9	3.1	2.5	9.4	139.9	524.4
B	168.3	3.1	0	0.6	0.6	0	0.8	17.5	145.7
C	341.0	34.5	4.8	6.0	2.1	1.0	3.6	16.3	272.7
D	599.3	0	0	0	0	1.0	4.1	28.1	566.1
E	392.6	34.2	3.5	5.0	4.9	3.8	6.8	45.0	289.4

NOTE: All Weights in Grams

APPENDIX 2

Hydrometer Analysis Data

Sample Number	Hydrometer Reading at 40^s	Temperature Correction Factor	Dispersion Coefficient	Corrected Reading	Hydrometer Reading at 6h 52m	Temperature Correction Factor	Dispersion Coefficient	Corrected Reading	Sand-Silt-Clay Percentages (for <500 μ only)	Date of Analysis
1	13	0	-7	6	8	+ .4	-7	1.4	88.0- 9.2- 2.8	29 Sept 76
2	13	0	-7	6	8.5	+ .4	-7	1.9	88.0- 8.2- 3.8	29 Sept 76
3	12.5	0	-7	5.5	8.5	+ .4	-7	1.9	89.0- 7.2- 3.8	29 Sept 76
4	13	0	-7	6	9	+ .4	-7	2.4	88.0- 7.2- 4.8	29 Sept 76
5	15	0	-7	8	9.5	+ .4	-7	2.9	84.0-10.2- 5.8	29 Sept 76
6	12.5	+1	-6	7.5	8	+1.6	-6	3.6	85.0- 7.8- 7.2	2 Oct 76
7	14.5	0	-7	7.5	9	+ .4	-7	2.4	85.0-10.2- 4.8	29 Sept 76
8	13	+1	-6	8	8	+1.6	-6	3.6	84.0- 8.8- 7.2	2 Oct 76
9	12	+1	-6	7	8	+1.6	-6	3.6	86.0- 6.8- 7.2	2 Oct 76
10	12	+1	-6	7	8	+1.6	-6	3.6	86.0- 6.8- 7.2	2 Oct 76
11	10	+1	-6	5	7.5	+1.6	-6	3.1	90.0- 3.8- 6.2	2 Oct 76
12	10	+1.2	-6	5.2	6.5	+1.8	-6	2.3	89.6- 5.8- 4.6	2 Oct 76
13	12	+1.2	-6	7.2	7.5	+1.8	-6	3.3	85.6- 7.8- 6.6	2 Oct 76
14	12	+1.2	-6	7.2	8	+1.8	-6	3.8	85.6- 6.8- 7.6	2 Oct 76
15	11	+1.2	-6	6.2	6.5	+1.8	-6	2.3	87.6- 7.8- 4.6	2 Oct 76
16	13.5	+1.2	-6	8.7	8.5	+1.8	-6	4.3	82.6- 8.8- 8.6	2 Oct 76
17	12.5	+1.2	-6	7.7	8	+1.8	-6	3.8	84.6- 7.8- 7.6	2 Oct 76
18	12	+1.2	-6	7.2	7	+1.8	-6	2.8	85.6- 8.8- 5.6	2 Oct 76
19	12	+1.2	-6	7.2	7	+1.8	-6	2.8	85.6- 8.8- 5.6	2 Oct 76
20	8.5	+1.2	-6	3.7	6.5	+1.8	-6	2.3	92.6- 2.8- 4.6	2 Oct 76
21	12	+1.4	-3	10.4	8	+2.2	-3	7.2	79.2- 6.4-14.4	20 Oct 76
22	12.5	+1.4	-3	10.9	7.5	+2.2	-3	6.7	78.2- 8.4-13.4	20 Oct 76

APPENDIX 2: continued

Sample Number	Hydrometer Reading at 40s	Temperature Correction Factor	Dispersion Coefficient	Corrected Reading	Hydrometer Reading at 6h 52m	Temperature Correction Factor	Dispersion Coefficient	Corrected Reading	Sand-Silt-Clay Percentages (for <500 μ only)	Date of Analysis
23	14	+ .6	-2.5	12.1	9	+ .8	-3	6.8	75.8-10.6-13.6	10 Nov 76
24	13.5	+ .6	-2.5	11.6	8	+ .8	-3	5.8	76.8-11.6-11.6	10 Nov 76
25	13.5	+ .6	-2.5	11.6	8	+ .8	-3	5.8	76.8-11.6-11.6	10 Nov 76
26	20.5	+ .6	-2.5	18.1	10	+ .8	-3	7.8	63.8-20.6-15.6	10 Nov 76
27	20	+ .6	-2.5	18.1	10.5	+ .8	-3	8.3	63.8-19.6-16.6	10 Nov 76
28	20.5	+ .6	-2.5	18.6	9	+ .8	-3	6.8	62.8-23.6-13.6	10 Nov 76
29	20.5	+ .6	-2.5	18.6	9.5	+ .8	-3	7.3	62.8-22.6-14.6	10 Nov 76
30	24	+ .6	-2.5	22.1	13	+ .8	-3	10.8	55.8-22.6-21.6	10 Nov 76
A	8	+1.4	-3	6.4	5.5	+2.2	-3	4.7	87.2- 3.4- 9.4	20 Oct 76
B	20	+1.4	-3	18.4	6.5	+2.2	-3	5.7	ORGANIC-PEAT	20 Oct 76
C	9	+1.4	-3	7.4	6	+2.2	-3	5.2	85.2- 4.4-10.4	20 Oct 76
D	5	+2.4	-1	6.4	5	+2.6	-1	6.6	86.8- 0 -13.2	21 Nov 76
E	8	+2.4	-1	9.4	6	+2.6	-1	7.6	81.2- 3.6-15.2	21 Nov 76

NOTE: All samples weighed 50.0 grams (air dry)

APPENDIX 3

Liquid Limit/Plastic Limit/Plasticity Index Analyses

Sample Number	Weight of Dish (W_c)	Wet Weight (W_1)	Oven-Dry Weight (W_2)	Liquid Limit $\frac{(W_1-W_2)}{(W_2-W_c)} = LL)$	Plasticity	Weight of Dish (W_c)	Wet Weight (W_1)	Oven-Dry Weight (W_2)	Plastic Limit $\frac{(W_1-W_2)}{(W_2-W_c)} = PL)$	Plasticity Index (LL-PL = PI)
1	13.9	29.2	27.2	15 %	no				0	0
2	16.8	30.5	28.1	21.2%	no				0	0
3	15.6	31.0	28.5	19.3%	no				0	0
4	13.8	29.6	27.7	19.7%	no				0	0
5	15.6	31.8	29.0	20.8%	no				0	0
6	15.6	32.9	30.6	15.3%	no				0	0
7	13.4	31.7	28.2	23.6%	no				0	0
8	16.0	32.7	29.7	21.9%	no				0	0
9	15.8	30.0	27.8	18.3%	no				0	0
10	17.0	31.9	29.4	20.1%	no				0	0
11	13.7	30.8	28.3	17.1%	no				0	0
12	16.9	35.2	32.4	18.1%	no				0	0
13	15.0	35.0	31.6	20.4%	no				0	0
14	14.6	34.0	31.4	15.4%	no				0	0
15	15.1	33.1	30.2	19.2%	no				0	0
16	15.2	33.1	30.8	14.7%	no				0	0
17	16.7	33.8	31.2	17.9%	no				0	0
18	15.5	35.6	32.4	18.4%	no				0	0
19	17.8	33.7	31.1	19.5%	no				0	0
20	14.1	32.2	29.4	18.3%	no				0	0
21	15.9	36.9	33.8	17.3%	no				0	0

APPENDIX 3: continued

Sample Number	Weight of Dish (W_c)	Wet Weight (W_1)	Oven-Dry Weight (W_2)	Liquid Limit $\frac{(W_1-W_2)}{(W_2-W_c)}$ = LL)	Plasticity	Weight of Dish (W_c)	Wet Weight (W_1)	Oven-Dry Weight (W_2)	Plastic Limit $\frac{(W_1-W_2)}{(W_2-W_c)}$ = PL)	Plasticity Index (LL-PL = PI)
22	15.5	32.6	29.4	23.0%	no				0	0
23	18.2	32.5	29.5	26.5%	yes	17.9	20.7	20.3	9.8%	16.7%
24	15.3	30.9	28.0	22.8%	no				0	0
25	15.7	30.7	27.2	30.4%	yes	15.9	19.5	18.9	10.4%	20 %
26	13.9	28.6	25.6	25.6%	no				0	0
27	17.2	30.3	27.1	32.3%	yes	14.8	17.7	17.2	11.5%	20.8%
28	12.5	29.5	26.3	23.2%	yes	12.4	16.2	15.7	8.0%	15.2%
29	16.2	29.6	27.2	21.8%	yes	13.1	17.4	16.2	2.4%	19.4%
30	12.0	22.5	20.0	31.2%	yes	17.1	19.6	19.2	12.2%	19.0%
A	15.9	35.9	32.4	21.2%	no				0	0
B	18.1	33.0	25.1	112.9%	yes	12.9	23.3	17.3	136.4%	0
C	13.3	31.9	29.6	14.1%	no				0	0
D	14.0	28.4	26.3	17.1%	no				0	0
E	17.9	33.5	31.2	17.3%	no				0	0

NOTE: Results with Liquid Limit Device.

All Weights in Grams.

APPENDIX 3: continued

Liquid Limit Determination

Sample Number	Weight of Dish (W_c)	Wet Weight (W_1)	Oven-Dry Weight (W_2)	Liquid Limit $\left(\frac{W_1-W_2}{W_2-W_c} = LL\right)$
1	14.0	39.7	35.6	19.0%
2	16.9	35.5	31.2	30.1%
3	15.7	41.5	40.8	2.8%
4	13.9	36.5	31.5	28.4%
5	15.7	34.6	30.3	29.5%
6	15.7	38.0	34.4	19.3%
7	13.5	36.7	32.0	25.4%
8	16.1	33.5	29.3	31.8%
9	15.9	34.5	31.0	23.2%
10	17.1	44.2	38.8	24.9%
11	13.8	37.8	33.7	20.6%
12	17.0	36.4	32.4	26.0%
13	15.1	45.9	40.8	19.8%
14	14.7	49.1	44.1	17.0%
15	15.2	64.7	56.2	20.7%
16	15.3	47.9	43.3	16.4%
17	16.8	45.1	41.0	16.9%
18	15.6	44.6	38.4	27.2%
19	17.9	44.6	39.5	23.6%
20	14.2	46.2	41.0	19.4%

NOTE: Results with Expedient Method.

All Weights in Grams.

APPENDIX 4: Precipitation Data 1873-1910 (in cm)

	WINTER				SPRING				FALL			
YEAR	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.
1873	3.51	----	4.47	-.35	8.84	----	8.94	1.09	7.37	----	10.16	-1.82
74	4.11	----	4.55	-.10	6.86	----	8.84	.20	9.04	----	10.44	-1.83
75	4.88	4.27	4.70	.92	7.29	8.28	8.99	-.26	8.81	8.76	11.00	-2.07
76	4.98	3.94	4.62	2.04	10.87	8.18	8.94	2.86	8.97	9.58	11.18	-2.15
77	3.81	4.44	4.67	1.99	7.54	8.46	8.51	2.65	9.68	9.78	11.13	-1.52
78	1.91	4.44	4.90	.04	8.36	9.63	8.26	3.26	11.38	9.78	11.10	.81
79	6.60	4.42	5.08	2.80	8.28	8.92	8.33	3.79	10.01	11.63	10.72	1.77
80	4.90	4.67	4.93	3.84	13.03	9.63	8.05	9.07	8.86	11.53	10.39	1.58
81	4.93	5.18	4.78	4.91	7.39	9.47	7.70	8.71	18.21	11.35	10.69	10.74
82	5.00	4.98	4.67	6.05	11.02	9.52	7.42	11.98	9.22	12.22	9.58	10.91
83	4.44	4.83	4.57	6.63	7.65	8.26	7.39	11.88	10.16	12.55	9.35	12.02
84	5.66	4.93	4.60	8.43	8.56	8.10	7.21	12.69	14.63	10.62	9.02	17.60
85	4.06	5.11	4.37	8.63	6.60	6.88	7.14	11.54	10.54	10.67	8.00	19.09
86	5.41	5.00	4.24	10.18	6.73	7.16	7.09	10.52	8.48	10.13	7.59	18.52
87	5.99	4.88	4.06	12.31	4.90	6.58	7.26	7.67	9.47	8.59	7.52	18.94
88	3.86	4.70	3.78	12.31	9.07	7.16	7.47	8.99	7.52	8.84	7.24	17.41
89	5.03	4.44	3.66	13.48	5.56	6.76	7.19	6.80	6.91	8.53	7.19	15.27
90	3.25	4.04	3.42	12.87	9.60	7.90	7.62	8.65	11.79	8.05	7.24	18.01
91	4.14	4.19	3.35	13.15	4.60	7.26	7.11	5.50	7.04	7.90	7.82	16.00
92	3.89	3.86	3.17	13.18	10.69	7.67	7.32	8.44	6.98	7.42	8.05	13.93
93	4.70	3.78	3.23	14.02	5.87	7.01	7.01	6.56	6.73	6.35	8.00	11.61
94	3.28	3.71	2.92	13.44	7.65	7.80	7.24	6.46	4.60	6.50	8.59	7.16
95	2.97	3.51	2.82	12.55	6.20	7.01	7.37	4.91	6.43	6.43	9.17	4.54
96	3.66	3.12	2.82	12.35	8.61	7.19	7.70	5.77	7.80	6.50	9.37	3.29
97	2.97	3.00	2.90	11.46	6.73	7.57	7.72	4.75	6.53	7.09	9.37	.77
98	2.74	2.95	2.82	10.34	6.50	7.24	7.65	3.50	7.19	9.27	9.65	- .09
99	2.67	2.67	2.84	9.15	9.75	6.86	7.85	5.50	7.44	9.58	9.55	- .70
1900	2.64	2.92	2.95	7.83	4.60	7.01	7.54	2.35	17.40	9.58	9.50	7.65

APPENDIX 4: continued

	WINTER				SPRING				FALL			
YEAR	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.
1901	2.29	2.74	2.95	6.26	6.68	7.32	7.49	1.28	9.35	10.67	8.46	7.95
02	4.29	2.64	----	6.69	7.57	7.16	----	1.10	6.50	11.28	----	5.40
03	1.78	2.72	----	4.61	8.00	8.18	----	1.35	12.70	9.47	----	9.05
04	2.24	3.12	----	2.99	8.99	8.61	----	2.59	10.44	9.14	----	10.44
05	2.95	2.74	----	2.08	9.65	8.26	----	4.49	8.36	9.70	----	9.75
06	4.37	2.97	----	2.59	8.79	8.36	----	5.53	7.77	8.43	----	8.47
07	2.41	3.48	----	1.14	5.84	7.92	----	3.62	9.30	7.72	----	8.72
08	2.87	3.40	----	.15	8.51	6.83	----	4.38	6.32	7.44	----	5.99
09	4.83	----	----	1.12	6.83	----	----	3.46	6.81	----	----	3.75
1910	2.54	----	----	-.20	4.19	----	----	-.10	7.01	----	----	1.71

APPENDIX 4: Precipitation Data 1925-1975 (in cm)

	WINTER				SPRING				FALL			
YEAR	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.
1925	----	----	----	----	7.04	----	6.91	- .66	8.36	----	8.76	-.41
26	3.05	----	3.51	- .36	7.19	----	6.96	-1.17	12.27	----	8.94	3.10
27	3.40	----	3.51	- .36	7.42	7.19	6.81	-1.45	8.41	9.91	8.46	2.74
28	3.91	3.10	3.58	.15	6.02	7.44	6.63	-3.12	13.49	9.45	8.48	7.47
29	2.87	2.90	3.56	- .38	8.28	7.19	7.16	-2.54	7.01	8.86	8.36	5.72
30	2.31	3.35	3.76	-1.47	8.28	6.83	7.19	-1.96	6.10	8.48	8.33	3.05
31	1.96	3.38	3.78	-2.92	5.89	7.09	7.44	-3.76	9.37	6.93	8.48	3.66
32	5.77	3.20	4.06	- .56	5.74	6.63	7.57	-5.72	6.45	7.62	8.84	1.35
33	3.96	3.91	3.68	0	7.21	6.50	7.98	-6.20	5.72	8.43	9.37	-1.70
34	2.01	4.11	3.63	-1.40	5.99	6.45	8.23	-7.90	10.49	8.05	9.55	.03
35	5.89	3.78	3.71	1.09	7.62	6.43	8.48	-7.98	10.16	8.48	9.07	1.42
36	2.90	3.76	3.51	.58	5.66	7.24	8.64	-10.01	7.49	8.90	8.84	.15
37	4.19	4.34	3.84	1.37	5.64	7.77	8.94	-12.06	8.56	9.02	8.86	- .05
38	3.78	3.63	3.73	1.75	11.33	8.41	9.12	- 8.43	12.32	8.56	8.76	3.51
39	4.93	3.91	3.66	3.28	8.59	8.69	8.51	- 7.54	6.58	9.60	8.03	1.32
40	2.41	3.61	3.58	2.29	10.80	9.55	8.36	- 4.44	7.80	10.24	8.28	.36
41	4.27	3.53	3.73	3.15	7.06	9.22	8.00	- 5.08	12.80	9.30	8.15	4.39
42	2.62	3.10	3.68	2.36	9.96	9.19	8.31	- 2.82	11.73	9.12	7.92	7.37
43	3.43	3.38	3.73	2.39	9.68	8.86	8.03	- .84	7.59	9.14	7.52	6.20
44	2.72	3.73	3.76	1.70	8.43	9.19	7.98	- .10	5.72	8.10	7.34	3.15
45	3.84	3.89	3.78	2.13	9.14	8.71	8.10	1.35	7.90	7.26	7.87	2.29
46	6.07	3.78	3.58	4.80	8.81	7.82	7.92	2.46	7.62	6.76	7.95	1.14
47	3.40	4.06	3.18	4.80	7.52	7.54	7.80	2.29	7.47	7.42	7.90	- .15
48	2.95	4.11	3.15	4.34	5.18	7.16	7.67	- .23	5.13	7.14	7.85	-3.78
49	4.04	3.66	3.12	4.98	7.09	7.44	7.70	- .84	9.02	7.75	8.28	-3.53
50	4.09	3.61	3.00	5.66	7.19	7.34	7.62	- 1.35	6.48	7.75	8.84	-5.82
51	3.81	3.73	2.90	6.07	10.19	8.10	7.80	1.14	10.69	7.90	9.07	-3.89
52	3.12	3.51	2.77	5.79	7.04	8.64	7.49	.48	7.47	8.33	8.99	-5.18
53	3.56	3.05	2.87	5.94	9.07	8.69	7.49	1.85	5.87	8.79	9.19	-8.08

APPENDIX 4: continued

	WINTER				SPRING				FALL			
YEAR	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.
1954	2.95	2.72	2.67	5.49	9.75	8.15	7.26	3.91	11.18	8.03	9.27	-5.66
55	1.83	2.72	2.57	3.91	7.34	8.00	6.96	3.56	8.69	7.98	9.04	-5.74
56	2.08	2.54	2.74	2.59	7.57	7.26	7.06	3.43	6.96	8.64	9.22	-7.54
57	3.18	2.46	3.02	2.36	6.25	6.58	6.93	1.98	7.14	9.35	9.37	-9.16
58	2.69	2.74	3.12	1.65	5.41	6.93	7.19	- .15	9.22	9.35	9.45	-8.71
59	2.59	2.84	3.02	.84	6.30	6.81	7.80	-1.55	14.68	9.93	9.50	-2.79
60	3.18	3.02	3.28	.61	9.12	6.98	8.03	- .13	8.74	10.41	8.79	-2.82
61	2.54	2.79	3.07	- .25	6.98	7.24	7.82	- .84	9.91	9.91	8.89	-1.68
62	4.17	2.69	3.38	.51	7.14	7.34	7.72	-1.40	9.52	8.74	8.84	- .91
63	1.45	2.74	3.35	-1.45	6.71	7.21	7.59	-2.39	6.71	9.12	9.22	-2.97
64	2.08	3.23	3.63	-2.77	6.71	7.04	8.08	-3.38	8.79	8.81	9.35	-2.95
65	4.14	3.23	3.81	-2.68	8.53	7.39	8.15	-2.54	10.67	8.48	9.25	-1.04
66	1.80	3.28	3.71	-1.17	6.15	8.38	7.98	-4.09	8.43	9.12	8.92	-1.37
67	4.14	3.66	----	- .43	8.92	8.71	----	-2.87	7.85	8.86	----	-2.29
68	1.80	3.43	----	-2.03	11.56	8.43	----	.99	9.83	8.66	----	-1.22
69	3.99	3.53	----	-1.45	8.38	8.38	----	1.68	7.54	8.84	----	-2.44
70	2.29	3.51	----	-2.57	7.21	7.80	----	1.19	9.60	9.93	----	-1.60
71	5.38	3.96	----	- .58	5.84	7.80	----	- .66	9.32	9.58	----	-1.04
72	4.06	3.68	----	.08	5.97	7.59	----	-2.39	13.39	9.60	----	3.58
73	4.06	4.01	----	.74	11.63	7.54	----	1.55	8.05	9.17	----	2.87
74	2.67	----	----	0	7.34	----	----	1.19	7.62	----	----	1.73
1975	3.84	----	----	.43	6.88	----	----	.38	7.49	----	----	.46

APPENDIX 5: Streamflow Data 1873-1910 (in m)

YEAR	AVG	FALL 5-yr. Mean	10-yr. Mean	Cum. Dev.
1873	1.28	----	1.19	.36
74	1.17	----	1.19	.60
75	1.08	1.17	1.20	.76
76	1.38	1.13	1.23	1.22
77	.95	1.09	1.19	1.25
78	1.09	1.19	1.19	1.41
79	.95	1.16	1.17	1.44
80	1.57	1.20	1.14	2.09
81	1.22	1.24	1.09	2.39
82	1.17	1.32	1.03	2.64
83	1.26	1.27	1.01	2.97
84	1.37	1.23	.94	3.42
85	1.34	1.18	.85	3.84
86	1.00	1.10	.78	3.92
87	.93	.96	.74	3.93
88	.90	.91	.72	3.90
89	.64	.83	.69	3.62
90	1.10	.84	.71	3.80
91	.59	.76	.71	3.46
92	.99	.73	.73	3.53
93	.50	.65	.70	3.10
94	.51	.65	.75	2.68
95	.66	.60	.79	2.41
96	.61	.62	.82	2.10
97	.73	.68	.83	1.91
98	.62	.77	.84	1.61
99	.78	.81	.84	1.47
1900	1.11	.80	.82	1.66
01	.81	.88	.76	1.54
02	.65	.90	----	1.27
03	1.04	.87	----	1.38
04	.88	.84	----	1.34
05	.96	.87	----	1.37
06	.66	.81	----	1.12
07	.83	.74	----	1.02
08	.73	.65	----	.82
09	.52	----	----	.41
1910	.49	----	----	- .02

APPENDIX 5: Streamflow Data 1941-1973 (in m^3/s per km^2) x 10^{-2}

	WINTER				SPRING				FALL			
YEAR	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.	AVG	5-yr. Mean	10-yr. Mean	Cum. Dev.
1941	.61	----	.63	-.09	.90	----	1.18	- .39	1.02	----	.66	.28
42	.77	----	.63	-.02	1.25	----	1.27	- .44	.96	----	.68	.51
43	.72	.61	.66	0	1.48	1.25	1.28	- .33	.64	.74	.67	.43
44	.54	.67	.65	-.16	.98	1.34	1.26	- .56	.45	.69	.69	.14
45	.44	.68	.66	-.43	1.62	1.34	1.27	- .23	.66	.63	.74	.07
46	.92	.62	.69	-.21	1.38	1.22	1.24	- .14	.74	.57	.73	.08
47	.84	.59	.67	-.07	1.45	1.18	1.20	- .17	.66	.59	.73	0
48	.49	.62	.63	-.27	.90	1.12	1.15	- .57	.36	.57	.71	-.37
49	.40	.55	.65	-.57	.73	1.19	1.13	-1.13	.52	.66	.72	-.58
50	.61	.58	.66	-.66	1.32	1.21	1.14	-1.09	.58	.71	.80	-.73
51	.57	.60	.70	-.77	1.76	1.29	1.19	- .62	1.17	.82	.82	-.30
52	1.04	.63	.73	-.45	1.37	1.36	1.15	- .55	.93	.90	.77	-.10
53	.61	.68	.71	-.54	1.26	1.34	1.15	- .58	.87	.90	.74	.04
54	.59	.69	.71	-.65	1.09	1.20	1.12	- .78	.94	.80	.70	.25
55	.83	.59	.70	-.51	1.25	1.08	1.07	- .82	.56	.70	.66	.08
56	.66	.57	.67	-.56	1.07	.96	1.13	-1.04	.71	.63	.69	.05
57	.59	.56	.71	-.67	.72	.92	1.15	-1.61	.43	.71	.67	-.25
58	.55	.60	.72	-.82	.69	1.05	1.25	-2.21	.55	.75	.69	-.44
59	.55	.63	.72	-.97	.89	1.08	1.28	-2.61	1.29	.73	.70	.12
60	1.05	.69	.75	-.62	1.86	1.52	1.34	-2.04	.79	.80	.65	.17
61	.82	.70	.71	-.50	1.26	1.21	1.31	-2.08	.61	.77	.68	.05
62	.86	.67	.72	-.32	1.36	1.27	1.33	-2.01	.74	.61	.69	.07
63	.63	.57	.72	-.40	1.01	1.22	1.34	-2.30	.39	.62	.74	-.27
64	.42	.61	.78	-.69	.67	1.20	1.53	-2.92	.52	.60	.78	-.48
65	.59	.56	----	-.80	1.74	1.21	----	-2.47	.84	.59	----	-.37
66	1.08	.55	----	-.42	1.29	1.29	----	-2.47	.52	.63	----	-.58
67	.62	.65	----	-.49	1.75	1.47	----	-2.01	.68	.68	----	-.63
68	.58	.65	----	-.61	.97	1.42	----	-2.33	.60	.74	----	-.77

APPENDIX 5: continued

YEAR	WINTER AVG	WINTER 5-yr. Mean	WINTER 10-yr. Mean	WINTER Cum. Dev.	SPRING AVG	SPRING 5-yr. Mean	SPRING 10-yr. Mean	SPRING Cum. Dev.	FALL AVG	FALL 5-yr. Mean	FALL 10-yr. Mean	FALL Cum. Dev.
1969	.92	.60	----	-.39	1.57	1.47	----	-2.04	.74	.78	----	-.75
70	.59	.65	----	-.50	1.53	1.40	----	-1.80	1.17	.91	----	-.32
71	.91	.75	----	-.30	1.51	1.76	----	-1.59	.71	.93	----	-.34
72	.87	----	----	-.12	1.43	----	----	-1.44	1.79	----	----	.22
1973	1.15	----	----	.33	2.78	----	----	.04	.72	----	----	.21

APPENDIX 6: HEC-2 Data

All of the HEC-2 data, to include both computer input and output, can be found at the office of DNR's Floodplain-Shoreland Management Section, 3rd floor of the Pyare Square Building on University Avenue in Madison, Wisconsin.

BIBLIOGRAPHY

Barry, R.G. and Chorley, R.J. Atmosphere, Weather, and Climate. Holt, Rinehart, and Winston, Inc. N.Y. 1970.

Benson, M.A. "Evolution of Methods for Evaluating the Occurrence of Floods." USGS Water Supply Paper 1580-A. 1962.

Bogardi, I. "Hydrological, Hydraulic, Soil Mechanical, and Meteorological Aspects of Models Devised for Determining the Degree of Protection Offered by Flood Levees." Bulletin of Int'l Assoc. of Scientific Hydrology. XVI, 3. 1971, pp. 45-49.

Brady, N.C. The Nature and Properties of Soils. MacMillan Publishing Co., Inc. 8th edition. N.Y. 1974, pp. 353-370.

Brinkmann, W.A.R. "Surface Temperature Trend for the Northern Hemisphere--Updated." Quaternary Research. Vol. 6, No. 3 Sept. 1976, pp. 355-358.

Brown, Harry. Soil Conservation Service. Madison, Wisconsin. Personal Communication. 1976.

Bryan, R.B. "Considerations on Soil Erodibility Indices and Sheetwash." CATENA. Vol. 3. 1976, pp. 99-111.

Bryson, R.A. and Lahey, J.F. The March of the Seasons. Dept. of Meteorology. University of Wisconsin. Madison, WI. 1958.

Chow, V.T. Open-Channel Hydraulics. McGraw-Hill Book Company. N.Y. 1959.

"Climatological Data--Wisconsin." National Oceanic and Atmospheric Administration. National Climatic Center. Asheville, N.C. (1925-1975).

Conger, D. "Estimating Magnitude and Frequency of Floods in Wisconsin." USGS Open-file Report, Madison, WI 1971.

Cooke, R.U. and Doornkamp, J.C. <u>Geomorphology in Environmental Management--An Introduction</u>. Clarendon Press. Oxford. 1974.

Corps of Engineers (C of E). "Letter-Subject: Section 205, Flood Control Reconnaissance Report, Wisconsin River at Portage, WI." C of E. St. Paul, MN. 24 Nov. 1971.

______________________________. "Flood Plain Information-Wisconsin River at Portage, Wisconsin." C of E. St. Paul, MN. 1972.

______________________________. "Water Surface Profiles." Generalized Computer Program, Users Manual. Hydrologic Engineering Center (HEC). C of E. Davis, CA. 1973.

<u>Daily River Stages</u>. US Weather Bureau. U.S. Department of Commerce. 1908-1976.

Dalrymple, T. "Flood Frequency Analyses." USGS Water Supply Paper 1543-A. 1960.

Dury, G.H. "Magnitude Frequency Analysis and Channel Morphology" in <u>Fluvial Geomorphology</u>., ed. by M. Morisawa. State University of N.Y. Binghamton, N.Y. 1973, pp. 91-121.

"Environmental Impact Report" (EIR). Columbia Generating Station Unit No. 2. Wisconsin Power and Light Co., Wisconsin Public Service Corp., and Madison Gas and Elec-

tric Corp. 1973.

"Environmental Impact Statement" (EIS). Columbia Generating Station, Columbia County, Wisconsin. Corps of Engineers, St. Paul, MN. 1974.

Graf, W.H. Hydraulics of Sediment Transport. McGraw-Hill Book Co. N.Y. 1971.

Gupta, A. and Fox, H. "Effects of High Magnitude Floods on Channel Form: A Case Study in the Maryland Piedmont." Water Resources Research. Vol. 10, No. 3. June 1974, pp. 499-509.

Hampton, T. Department of Natural Resources Floodplain-Shoreland Management Section. Personal Communication. 1976.

Herron, W.H. "Profile Surveys of Rivers in Wisconsin." USGS Water Supply Paper 417. 1917.

Hindall, S.M. "Measurements and Prediction of Sediment Yields in Wisconsin Streams." USGS Water Resources Investigations 54-75. Madison, WI. 1976.

Hjulström, F. "Studies of the Morphological Activity of Rivers as Illustrated by the River Fyris." reprint from Bull. Geol. Inst. of Uppsala (1935) in Landforms and Geomorphology. ed. by C.A.M. King. Dowden, Hutchinson, and Ross. N.Y. 1975, pp. 274-287.

Institute of Environmental Studies (IES). "Documentation of Environmental Change Related to the Columbia Generating Station: Seventh Semi-annual Report." IES Report 62.

University of Wisconsin. Madison, WI. 1976.

Jahns, R.H. "Geologic Features of the Connecticut Valley, Massachusetts, as Related to Recent Floods." USGS Water Supply Paper 996. 1947.

Kalnicky, R.A. "Climate Change Since 1950" in Annals of the AAG. Vol. 64, No. 1. 1974, pp. 100-112.

Kamper, D. Soil Conservation Service Engineering. Madison, WI. Personal Communication. 1976.

Kates, R.W. Hazard and Choice Perception in Flood Plain Management. University of Chicago Dept. of Geography Research Paper No. 78. Chicago. 1962

Kézdi, Afpád. Handbook of Soil Mechanics, Volume 1 Soil Physics. Elsevier Scientific Publishing Co. and Akadémiai Kiadó. Budapest. 1974.

Knox, J.C. "Valley Alluviation in Southwestern Wisconsin." Annals of AAG. Vol. 62, No. 3. Sept. 1972, pp. 401-410.

Knox, J.C., Bartlein, P., Hirschboek, K., and Muckenhirn, R. The Response of Floods and Sediment Yields to Climatic Variation and Land Use in the Upper Mississippi Valley. IES Report 52. University of Wisconsin. Madison, WI. 1975.

Krug, W. United States Geological Survey. Madison, Wisconsin Personal Communication. 1976.

Lamb, H.H. "Climate in the 1960s." The Geographical Journal. Vol. 132, Part 2. June 1966, pp. 183-212.

________. Climate: Present, Past and Future, Volume 1 Funda-

mentals and Climate Now. Methuen and Company. London. 1972.

Lambe, T.W. Soil Testing for Engineers. John Wiley and Sons, Inc. N.Y. 1951

Leliavsky, S. An Introduction to Fluvial Hydraulics. Constable and Company, Ltd. London. 1955.

Linsley, R.K., Kohler, M., and Paulhus, J. Hydrology for Engineers. McGraw-Hill Book Co. N.Y. 1958

Lodina, R.V. and Chalov, R.S. "Effects of Tributaries on the Composition of River Sediments and on Deformation of the Main Channel." Soviet Hydrology. Issue 4. 1971, pp. 370-375.

Malik, L.K. "Backwater Phenomena in the Rivers of the West Siberian Plain." Soviet Hydrology. Issue 1. 1971, p. 75.

Martin, L. The Physical Geography of Wisconsin. 3rd edition. University of Wisconsin Press. Madison, WI. 1965. (2nd edition 1932).

Mason, B.J. "Towards the Understanding and Prediction of Climatic Variations." Quarterly Journal of the Royal Meteorological Society. Vol. 102, No. 433, July 1976.

Mead, D.W. "The Flow of Streams and the Factors that Modify It, with Special Reference to Wisconsin Conditions." Regents of University of Wisconsin Bulletin. No. 425. Engineering Series. Vol. 6, No. 5. 1911, pp. 175-366.

Namias, J. "Climatic Anomaly Over the U.S. During the 1960s." Science. Vol. 170. 1970, pp. 741-743.

Nelson, J.G. "Some Effects of Glaciation on the Susquehanna River Valley." Annals of the AAG. Vol. 155, No. 3.

Sept. 1975, pp. 404-448.

Novak, I. "Predicting Coarse Sediment Transport: The Hjulström Curve Revisited" in Fluvial Geomorphology. ed. by M. Morisawa. State University of N.Y. Binghamton, N.Y. 1973, pp. 13-25.

Parrett, C. "Floodplain Management in Montana" in Hydraulic Engineering and the Environment. 21st Annual Hyd. Div. Spec. Conf. 1973.

Rozenberg, L.I. "Effects of Variable Backwater on Unsteady Flow in Rivers." Soviet Hydrology. Issue 3. 1972, pp. 209-213.

Schmied, R.B. "A Case Study of Public Information and Participation in the Siting of the Columbia Generating Plant." M.S. Thesis University of Wisconsin. Madison, WI. 1973.

Schmudde, T.H. "Some Aspects of Land Forms of the Lower Missouri River Floodplain." Annals of the AAG. Vol. 53, No. 1. March 1963, pp. 60-73.

Schumm, S.A. "Geomorphic Thresholds and Complex Response of Drainage Systems" in Fluvial Geomorphology. ed. by M. Morisawa. State University of N.Y. Binghamton, N.Y. 1973, pp. 299-310.

Shaver, M.P. "A Preliminary Assessment of the Impact of the Columbia Generating Station on Local Land Use and Land Ownership Patterns in Pacific Township, Columbia County Wisconsin." M.S. Thesis. University of Wisconsin. Madison, WI. 1976.

Shen, H.W. "Flow Resistance Over Short Simulated Vegetation and Various Tall Simulated Vegetation Groupings on Flow Resistance and Sediment Yield" in Environmental Impact on Rivers. ed. by H.W. Shen. H.W. Shen. Ft. Collins, CO. 1973, pp. 3-1 to 3-51.

Sherrar, L. Manager, Wisconsin Valley Improvement Authority. Personal Communication. 19 April 1976.

__________. Wisconsin River Hydrology Conference. 6 October 1976.

Simons, D.B. "Open Channel Flow" in Introduction to Fluvial Processes. ed. by R.J. Chorley. Methuen and Co. Ltd. London. 1969, pp. 124-145.

Soil Conservation Service (SCS). Handbook of Channel Design for Soil and Water Conservation. USDA. SCS TP-61. 1954.

______________________________. Planning and Design of Open Channels. Technical Release No. 25. USDA SCS Engineering Division. 1964.

Trewartha, G.T. The Earth's Problem Climates. The University of Wisconsin Press. Madison, WI. 1961.

Upper Mississippi River Comprehensive Basin Study (UMCBS). Volumes 3, 4, and 5. Corps of Engineers. 1970.

Ward, R.C. Principles of Hydrology. McGraw-Hill Publishing Co. London. 1967.

"Water Resources Data for Wisconsin." U.S. Department of the Interior Geological Survey. 1961-1975.

Willard, D. Columbia Site Impact Study Group. Madison, Wisconsin. Personal Communication. 1977.

Willett, H.C. "Do Recent Climatic Trends Portend An Imminent Ice Age?" in Atmospheric Quality and Climatic Change. ed. by R.G. Kopec. University of N.C.-Chapel Hill. Chapel Hill, N.C. 1976, pp. 4-39.

Wischmeier, W.H. "Upslope Erosion Analysis" in Environmental Impact on Rivers. ed. by H.W. Shen. H.W. Shen. Ft. Collins, CO. 1973, pp. 15-1 to 15-26.

Wolman, M.G. "A Cycle of Sedimentation and Erosion in Urban River Channels." Geografiska Annaler Series A, No. 49. 1967, pp. 385-395.